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ORIGINAL ARTICLES.

The Dykes of the Ards Peninsula, Co. Down.

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(PLATES VIII–X.)

(*Concluded from p. 111.*)

Vogesite.

THE vogesites are of two distinct types, one of which will be designated type A and the other type B.

Type A.

The vogesites of type A show resemblances to the hornblende-porphyrites, towards which they grade by the occasional presence of felspar phenocrysts. They possess a typical panidiomorphic structure. Hornblende, which is similar to that of the porphyrites, builds elongated crystals which may be seven or eight times as long as broad and vary in length from about 2 or 3 mm. to 0·08 mm. or less. The matrix is formed of small lath-like crystals of felspar, amongst which potash-felspar (orthoclase or anorthoclase) predominates, plagioclase also being present. The felspars are stained with haematite, particularly round their margins, so that they stand out in relief. Quartz and green glass occur interstitially. Magnetite and apatite are again present as accessories, but this time the magnetite appears as small octahedral crystals, whilst the apatite prisms are long and needle-like. The structural characteristic of the rock is the tendency of all the minerals to show form and, with the exception of quartz and magnetite, to be elongated. The larger hornblende crystals have a parallel arrangement due to flow. The serpentinous or chloritic pseudomorphs, seen in the porphyrites, are here even more evident and give definite lozenge-shaped and elongated sections exhibiting the meshwork structure characteristic of olivine. They are again surrounded by reaction rims of hornblende prisms, in which the hornblende is exactly similar to that in the main part of the rock.

These vogesites are on the whole fresh, but the hornblende has sometimes undergone a certain amount of alteration to chlorite and in some of the rocks has entirely decomposed. The felspars have usually partly altered to sericite, particularly in the interior, a clear margin remaining. This probably indicates zoning.

Some of the rocks are characterized by what appear to have been small irregular cavities of the nature of druses. Felspar crystals project into them and they are filled with quartz and calcite. They do not resemble the ocelli of the crushed series, with their characteristic rim of biotite flakes.

A curious rock (No. 288), in some ways allied to these vogesites, outcrops at the point north of the Butterlump Stone and strikes towards Burial Island. It is red in colour and forms a wall-like dyke. It is composed essentially of felspar and green glass, with some calcite. The felspars appear as small laths, with an average size of 0·4 mm. by 0·08 mm., amongst which orthoclase or anorthoclase predominates. The felspar laths are arranged quite irregularly and frequently cross one another at right angles, the interstices between them being occupied by green glass. Apatite and magnetite are present as accessories. The rock is similar to the vogesites, type A, with the omisson of hornblende and considerably more glassy base. It was analysed in order to gain some idea as to the composition of the glass, which has a refractive index of approximately 1·62, roughly that of a basaltic glass. The fine grain of the rock makes it impossible to determine the mode with any degree of accuracy; the glass, however, forms approximately 36 per cent of the rock by volume. The analysis and norm are as follows :—

Analysis.		Norm.		Partial Mode (percentage volume).	
SiO_2	50·40	quartz	4·92	glass	36
Al_2O_3	17·05	orthoclase	10·56	felspar, calcite, and iron-ore	64
Fe_2O_3	1·32	albite	33·01		
FeO	6·15	anorthite	9·73		
MgO	5·30	corundum	5·2		
CaO	5·65	hypersthene	21·62		
Na_2O	3·94	magnetite	1·86		
K_2O	1·80	ilmenite	2·28		
H_2O +	3·60	apatite	·34		
H_2O −	·50	calcite	6·4		
CO_2	2·80				
TiO_2	1·24				
P_2O_5	·18				
S	trace				
MnO	trace				
	99·93				

Symbol II″.5.2.4.

Specific gravity = 2·726 ± ·003 at 4° C.

From an examination of the norm it is apparent that the glass includes normative hypersthene, corundum, a small amount of felspar and possibly quartz, corundum being present in surprisingly

large amount. It is evidently quite abnormal in composition. The ratio of albite to orthoclase in the norm strongly suggests that the potash-felspar present in the rock is anorthoclase.

Type B.

The vogesites of type B, although characterized by the same minerals as those of type A, differ from them in structure; the felspar matrix is more coarsely crystalline and they are not panidiomorphic. Plagioclase (albite and oligoclase) is euhedral, whilst the potash-felspar, which gives the patchy extinction suggestive of anorthoclase, is elongated in section and anhedral.

Hornblende, when most abundant, forms crystals which are almost as broad as long. In other cases it is elongated and needle-like, in which case it is considerably less coarsely crystalline than the felspar matrix, several small acicular crystals then being enclosed in a single felspar. The hornblende is usually zoned, the central part being browner in colour. Pleochroism in the centre zone is, X = pale yellowish green, Y = Z = brownish green; and in the outer zone, X = pale yellowish green, Y = Z = olive green. The outer zone exhibits the highest extinction angle in the prism zone, 22° being the maximum measured. Colourless and bluish-green outgrowths of amphibole, in optical continuity with the hornblende, are common. They are best developed on the terminal faces, but can sometimes be seen as additions to the clinopinacoid or filling cracks. These outgrowths have serrated boundaries and are often zoned, being bluish-green in colour where in contact with the central hornblende and colourless at their outer edges. The zones are well-defined, the change from one to another being abrupt. They have a lower refraction than the central hornblende, there being the most noticeable difference in the maximum refractive indices. The outgrowths are probably actinolite and tremolite and resemble those of tremolite described by Flett[1] from the lamprophyres of the Carn Dearg type.

Porphyritic and glomeroporphyritic groups of diopside or leucaugite occur sporadically in rocks of this type. The crystals are usually considerably larger in size than those of hornblende and are frequently altered to carbonates. At times the pyroxene is more abundant and then appears as small grains, which have been largely resorbed. Chloritic or serpentinous pseudomorphs, rimmed by hornblende, are again present and sometimes common. They are usually quite irregular in shape. Accessories are pyrite, apatite with a needle-like form, and rarely magnetite.

Some of the rocks are vesicular, the vesicles being filled with epidote, calcite, quartz, and felspar. Quartz, felspar and epidote frequently exhibit form, crystals of the latter having a radial arrange-

[1] "The Geology of the country round Blair Atholl, Pitlochry, and Aberfeldy": *Mem. Geol. Surv. Scotland*, 1905, 127.

ment ; calcite is interstitial. These amygdales in no way resemble ocelli.

Vogesites of type B are characteristically fresh, but carbonates may be present in small amount, replacing the felspars, and some epidote and chlorite are usually present.

Specimen No. 86, from a dyke on the headland south of Kircubbin, was selected for analysis as being the coarsest in grain and one of the least variable in mineral composition. It should be noted, however, that it is richer in hornblende than the average rock of this type and some of the hornblende has undergone a curious type of alteration, having been partly replaced by tremolite with similar optical orientation. The alteration extends along the cleavage planes, and magnetite, haematite and quartz have crystallized out as a result. Outgrowths of tremolite from the terminal faces of the hornblende are here very small. Quartz and potash-felspar appear in fine micrographic intergrowth in places in the matrix. The analysis, norm and mode of this rock are as follows :—

Analysis.		Norm.		Mode (percentage volume).	
SiO_2	49·40	orthoclase	8·34	felspar	32·7
Al_2O_3	12·85	albite	23·06	hornblende	48·4
Fe_2O_3	1·98	anorthite	18·63	quartz	2·7
FeO	6·31	diopside	8·64	chlorite and some epidote	18·3
MgO	12·04	hypersthene	19·66		
CaO	7·40	olivine	10·77		
Na_2O	2·65	magnetite	2·78		
K_2O	1·35	ilmenite	2·13		
H_2O +	3·10	apatite	3·4		
H_2O −	·20	calcite	2·3		
CO_2	1·00				
TiO_2	1·10				
P_2O_5	·24				
S	traces				
MnO	·31				
	99·93				

Symbol III.5.3.4.
1(2).2.(1)2.2.

Specific gravity = 2·834 ± ·002 at 4° C.

By computing an average composition for the hornblende calculated as a norm and subtracting it from the norm of the rock, it can be shown, as before, that the potash-felspar is rich in soda, having the composition of anorthoclase. For this purpose one quarter of the felspar is reckoned as plagioclase, this being an overestimate.

The vogesite from South Bay, the age of which is doubtful, may be mentioned here. Petrologically it resembles type B, but has some tendency to the panidiomorphic structure, and is highly charged with carbonates. Its chief interest lies in the fact that there are outgrowths of a blue amphibole from the original hornblende. Similar outgrowths have been described by Seymour[1]

[1] H. J. Seymour, " On the occurrence of a blue amphibole in a hornblende-kersantite from co. Down " : GEOL. MAG., 1900, 257.

in a rock from the same locality and assigned by him to the group of soda-amphiboles, of which riebeckite and arfvedsonite form typical examples. The rock (No. 196) examined by the writer differs from that described by Seymour in that biotite is absent and the predominant felspar is orthoclase or anorthoclase. It is of medium grain and the hornblende crystals are elongated, the largest being 0·2 mm. broad, and varying from two to five times this in length. Outgrowths of blue amphibole are here only seen as additions to the terminal faces (Seymour records additions to the clino-pinacoid) and are always small, only occasionally reaching 0·1 mm. in length. They are in crystallographic continuity with the original hornblende, the cleavage in the two being parallel, but more sharply defined in

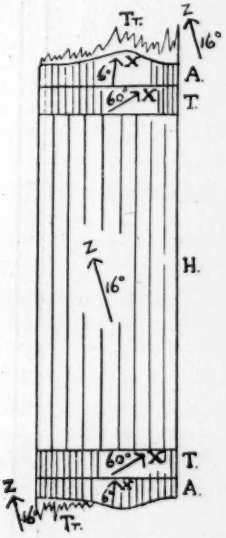


Fig. 3.—A crystal of hornblende with outgrowths of blue amphibole and tremolite. H = hornblende; T = zone which resembles torendrikite; A = arfvedsonite; Tr = tremolite.

the blue amphibole. The outgrowths are zoned, being paler in colour where in contact with the hornblende. At the outer edges they are strongly pleochroic, as follows: X = violet blue, Y = greenish blue, Z = straw colour, with the absorption X > Y > Z. They extinguish in the opposite direction to the hornblende, maximum extinction of 11° having been measured in the prism zone; this extinction direction being that of the fast ray X (see Fig. 3). The birefringence is weak and there is incomplete extinction in white light, indicating strong dispersion of the bisectrices.

In the paler zone the extinction is greater and the angle X ∧ c approximates to 60°. It is also noticeable in this inner zone that the pleochroic axes do not coincide with X, Y, Z, the maximum

absorption being parallel to the crystallographic axis c. Pleochroism is bluish-green parallel to c and violet-gray at right angles. The refractive indices are lower than those for hornblende and the berefringence, though weak, is greater than that in the outer zone.

It is not possible to make exact optical determinations, owing to the small size of the outgrowths, but it seems likely that the more deeply coloured zone is arfvedsonite ; whilst the inner paler one shows some resemblances to torendrikite.

On many of the crystals there is an additional exceedingly narrow outer margin of tremolite, in optical continuity with the original hornblende. It has a lower refractive index than that of the neighbouring blue amphibole.

Spessartite.

These rocks, which are typically trachytic in texture, are classified as spessartites since, in every case in which the matrix is not too fine grained for a discrimination to be made between the felspars, plagioclase appears to predominate. Potash-felspar, possibly anorthoclase, is always present in considerable amount, however, and some diffidence is felt in using the name " spessartite ". It is not impossible that these rocks differ from those described as vogesites rather in the variety of hornblende they contain and their trachytic matrix than in the composition of the predominant felspar, in which case they may themselves include both spessartites and vogesites.

Hornblende forms elongated porphyritic crystals which are two or three times as long as they are broad and have a maximum length of 2 or 3 mm. It is pale brown in colour and pleochroic, with X = pale yellowish brown, Y = Z = light brown. Zoning is sometimes exhibited. Though distinctly browner than the central brownish zone of the hornblende in the vogesites, it has a similar extinction angle, 20° being the maximum extinction measured in the prism zone. These hornblende phenocrysts are well formed, and have a parallel arrangement due to flow. They are often partly decomposed and are sometimes represented by pseudomorphs of chlorite, calcite, and quartz.

The matrix is mainly felspathic with some needle-like brown hornblende, interstitial quartz and a minute quantity of green glass. Both the lath-like felspar and the hornblende of the matrix show distinct signs of flow around the hornblende phenocrysts. The plagioclase is albite, being optically positive with $\gamma < 1{\cdot}54 > 1{\cdot}537$, $\alpha < 1{\cdot}537 > 1{\cdot}536$ and having a maximum extinction of 17° in the zone perpendicular to (010).

The texture of these rocks suggests that the porphyritic hornblende is of intratelluric origin.

Specimen No. 268 from a dyke near the Butterlump Stone, south of Ballyhalbert, was selected, to represent the group, for analysis.

In it the hornblende is mainly fresh and the matrix exceedingly fine grained. It is impossible to estimate the proportion of felspar, quartz, and hornblende in the groundmass, but felspar greatly predominates. The analysis, norm and partial mode are as follows :—

Analysis.		Norm.		Partial Mode (percentage volume).	
SiO_2	54·30	quartz	3·18	hornblende	15·8
Al_2O_3	15·46	orthoclase	11·12	matrix, mainly felspar	
Fe_2O_3	1·86	albite	36·15	with hornblende	
FeO	5·20	anorthite	17·51	and quartz	84·2
MgO	5·61	hypersthene	20·86		
CaO	5·50	magnetite	2·78		
Na_2O	4·30	ilmenite	1·67		
K_2O	1·94	apatite	·34		
H_2O +	2·80	calcite	3·2		
H_2O −	·44				
CO_2	1·35				
TiO_2	·90				
P_2O_5	·22				
S	trace				
MnO	·22				
	100·10				

Symbol II.5″.3.4.

Specific gravity 2·761 ± ·003 at 4° C.

The proportion of normative albite to orthoclase is greater here than in the analysed vogesite and porphyrite and the percentage of modal hornblende distinctly smaller than in the porphyrite. Consequently it can be inferred that the felspar in the spessartite includes a higher percentage of albite, either as plagioclase or included in anorthoclase. The difference, however, is very small when regarded as a basis for classification.

Felspar-Porphyry.

The felspar-porphyries are composed almost entirely of felspar, with a preponderance of anorthoclase. They are characterized by phenocrysts and glomeroporphyritic groups of anorthoclase and albite, the individual crystals of which vary from 1 to 2 mm. in length. Anorthoclase is almost square in section, whilst the albite crystals are approximately twice as long as they are broad.

The matrix consists of euhedrons of anorthoclase and albite, together with a certain amount of finely crystalline interstitial material composed of felspar and quartz. The felspars are mostly fresh and the matrix includes only a small amount of calcite. No fresh ferro-magnesian mineral is present. Rare elongated pseudomorphs of chlorite and carbonates, however, probably represent hornblende phenocrysts, whilst small flakes of chlorite possibly indicate the former presence of acicular hornblende in the groundmass. The rocks are in this way allied to the hornblende types previously described.

Apatite and pyrite are accessory minerals; the latter is quite irregular in shape, whilst the former occurs in small but rather

broad prisms and, rarely, needles. Apatite is present both in the matrix and in the felspar phenocrysts, which are sometimes crowded with such inclusions.

(ii) Biotite-Pyroxene Type.

Pyroxene-minette (Type A) and Kersantite.

Minette is much more common than kersantite and the coarser-grained rocks are usually of this type. Characteristic minerals in both varieties are monoclinic pyroxene, biotite, anorthoclase, plagioclase, and quartz, with apatite, magnetite, and pyrite as accessories. Pseudomorphs after olivine are common in some of the rocks. The mafic components form phenocrysts, whilst the felspars and quartz occur in the matrix only, the latter being interstitial. The plagioclase is usually albite, but is sometimes an acid oligoclase. Many of these rocks are highly charged with carbonates, which are present as pseudomorphs after pyroxene and olivine and in the matrix.

Coarseness of grain does not altogether depend on the size of the intrusion, dykes of similar thickness differing greatly in this respect. The felspars in the coarser type are anhedral and may measure as much as 1 mm. across, whilst in the finer-grained rocks they have a sheaf-like grouping or occur as minute laths, the interstices being filled with green glass and quartz. They are frequently zoned, there being a central zone of albite and an outer zone of anorthoclase.

The pyroxene is of the variety characteristic of lamprophyres, being colourless or pale green in thin section and having an almost equal development of prism and pinacoid faces, so that it gives almost regular octagonal cross sections. It is probably in some cases diopside and in others an augite which differs but slightly from diopside in composition. In the former case $\gamma - \alpha = \cdot 029$ and in the latter $\gamma - \alpha = \cdot 024$ or $\cdot 026$. Both are optically positive with $2V = 58°$ approximately. Owing to the difficulty of distinguishing between two varieties which are so similar, the pyroxene will be termed diopside indiscriminately.

Zoning is common and in the colourless pyroxene $Z \wedge c = 43°$ in the central zone and increases by one or two degrees in the outer zones. Occasionally crystals have the same extinction angle in an inner and outer zone, with a slightly higher extinction in intermediate zones.

The pale green variety is pleochroic with X = pale green, Y = Z = pale yellowish green, the colour frequently being restricted to a central area. The refractive indices are higher than in the colourless diopside and $Z \wedge c = 56°$. The colour, pleochroism, and extinction angle indicate the presence of soda.

Diopside forms crystals which vary in length from 2 mm., or exceptionally more, down to 1 mm. or less and are characteristically

about twice as long as they are broad. In some rocks, however, they are more elongated, the length being from five to eight times the breadth. They have their most perfect development in rocks with the finest felspar matrix. Where the groundmass is coarser in grain, although often more abundant, they have undergone resorption and frequently only small grains remain.

Crystals of diopside are sometimes replaced by biotite along their cleavage planes, so that the cleavage of the biotite is parallel to the *c* axis of the diopside and the biotite presents a brick-like appearance. This replacement may have proceeded to such an extent that only minute grains, in optical continuity, remain to suggest the former presence of diopside. (See Pl. IX, Fig. 3.) Rectangular groups of biotite crystals with this block-like arrangement are the result of complete replacement of the pyroxene. (See Pl. IX, Fig. 4.) Basal sections of biotite sometimes enclose optically-continuous grains of diopside.

This replacement suggests there was reaction between the diopside and a magma rich in alkalies, and probably much of the biotite originated in this way. The blocky appearance of the biotite resembles that figured by Bowen [1] as due to a similar replacement.

In the rock (No. 178) from the point north of Bar Hall, phenocrysts of diopside are surrounded by acicular crystals of anthophyllite. They measure 0·06 mm. in greatest length and are arranged radially around the diopside, having their best development on faces in the prism zone.

Biotite in thin flake-like crystals, the largest of which measure 1 cm. and the smallest 0·05 mm. across, exhibits a combination of the forms {110} {010} {001}, the basal flakes being elongated parallel to the edge (010) (001). It is pale in colour and characteristically zoned, having a dark margin and sometimes a dark interior in addition, in which case the interior is usually of a redder colour than the margin. Flakes frequently show re-entrants due to resorption, in which case the dark marginal biotite follows the embayed outline of the crystals rather than the hexagonal form of the central zones and thus appears to have been added after resorption ceased. The darker zones have a higher refractive index and are probably richer in iron than the pale biotite. Pleochroism is strong: X = pale yellow, Y = Z = brown. The refractive indices of the central reddish-brown zone, measured on a basal flake, are $\beta = 1{\cdot}598$, $\gamma = 1{\cdot}6$.

Lozenge-shaped and rounded pseudomorphs of serpentine, calcite, and quartz represent olivine. They are always rimmed tangentially by biotite flakes, an outer layer of which sometimes has the appearance of floating away from the central pseudomorph. The rounding of many of the pseudomorphs and their curved re-entrants indicates resorption of the original mineral. Where

[1] N. L. Bowen, "Genetic Features of Alnoitic Rocks at Isle Cadieux, Quebec," *Amer. Jour. Sci.*, iii, 1922, pl. 1, *e*. 1.

several pseudomorphs occur in contact, representing a glomeroporphyritic group of olivine, the biotite rim appears around the group but not between adjacent crystals. This biotite rim, so frequently described as characteristic in lamprophyres, is here quite evidently formed by reaction between the olivine and a magma rich in alkalies.

Flow-structure is well exhibited by the parallelism of the larger biotite flakes, the brick-like groups of biotite and the diopside

FIG. 4.—Drusy cavity in a kersantite (No. 233) showing the replacement of quartz and felspar by calcite. C = calcite; F = felspar; Q = quartz; B = biotite. Dots within the margin of the felspar represent speckling with calcite.

phenocrysts. This, together with the fact that both diopside and mica are well crystallized in rocks in which felspar is almost spherulitic in its development indicates that the diopside and biotite were in existence before intrusion.

Small druses, with a maximum width of 2 mm. are present in some of the rocks of this type. Euhedral crystals of felspar and

quartz extend into these structures, which are filled centrally with calcite. The quartz partly surrounds the felspar and often exhibits curiously crenulated and embayed margins where in contact with calcite, which encloses small isolated fragments of optically continuous quartz also with strikingly irregular boundaries. There can be little doubt that the calcite has partly replaced quartz (See Fig. 4.) The residual quartz fragments are sometimes exceedingly small, and in parts there has been complete replacement, so that perfect felspar crystals are surrounded by calcite. At times this replacement has proceeded to the felspars, which then have slightly serrated borders and a marginal speckling of minute calcite grains.

Although the felspars in the minettes and kersantites are often remarkably fresh, yet there is usually a sprinkling of carbonates, whilst diopside and olivine may be represented by calcite pseudomorphs. The calcite in the matrix is due to replacement similar to that noted in the druses. Here again quartz is first replaced, so that calcite now frequently occupies small wedge-shaped areas between the felspar laths and at first sight appears to be the final product of consolidation from the magma. Close inspection, however, often reveals some residual quartz and the fact that the edge of the felspar in contact with calcite is minutely fingered and speckled with calcite. Quartz xenocrysts have sometimes been similarly attacked. It seems, therefore, that in the uncrushed dykes carbonates are present in the matrix owing to replacement first of quartz and then of felspar. Many of the rocks have no appearance of weathering and this replacement may be attributed to the action of residual solutions, charged with carbonates, immediately after intrusion.

The rounded structures rimmed by biotite and usually described as ocelli (the views as to the origin of which have been summarized by Read [1]) are present in many of the diopside-minettes and kersantites, sometimes in addition to the druses described above. They vary from 0·4 mm. to 1·2 mm. across. Although frequently oval in section, they sometimes have an elongated six- or eight-sided form which suggests crystal outline and occasionally two such structures occur in contact. They contain quartz, felspar, and calcite which in general have no definite arrangement. At times, however, the felspars tend to project from the biotite rim towards the centre. There is no real evidence in these rocks as to the origin of these forms, although in their persistent biotite rim they differ from the structures regarded as druses. This rim resembles that round the olivines, where it is due to reaction between the mineral and magma. If, in the case of the " ocelli ", it is of the same nature, then these structures are evidence of the existence of a mineral

[1] H. H. Read, " The Mica-Lamprophyres of Wigtownshire " : GEOL. MAG., LXIII, 1926, 428.

which became unstable in the magma at an early stage, its form being at times preserved by the development of biotite.

A minette from Horse Island (No. 47) with a coarse-grained matrix was selected for analysis. It exhibits well the replacement of diopside by biotite, and the residual diopside has been largely resorbed. The analysis, norm, and mode are as follows :—

Analysis.		Norm.		Mode (percentage volume).	
SiO_2	48·80	orthoclase	16·12	quartz	2·0
Al_2O_3	12·80	albite	23·06	felspar	44·5
Fe_2O_3	1·64	anorthite	14·46	diopside	17·4
FeO	5·98	diopside	7·53	biotite	23·9
MgO	10·35	hypersthene	12·74	magnetite	1·3
CaO	7·65	olivine	12·64	calcite with a little chlorite	9·9
Na_2O	2·73	magnetite	2·32		
K_2O	2·74	ilmenite	2·13		
$H_2O +$	3·00	pyrite	·24		
$H_2O -$	·50	apatite	1·34		
CO_2	1·70	calcite	3·9		
TiO_2	1·10				
P_2O_5	·49				
S	·12				
MnO	·28				
	99·88				

Symbol III.5.3.3 (4).
1(2).(2)3.2.2.

Specific gravity = 2·819 ± ·003 at 4° C.

The rock contains very little plagioclase and the fact that the norm shows a higher proportion of albite than orthoclase, in spite of the fact that there is 24 per cent of modal biotite, indicates that the potash-felspar has the composition of anorthoclase.

A rock from near the Butterlump Stone (No. 276) was selected for analysis to represent the type with a sheaf-like felspar matrix. The analysis, norm and mode are as follows :—

Analysis.		Norm.		Mode (percentage volume).	
SiO_2	48·25	orthoclase	21·68	felspar	56
Al_2O_3	13·84	albite	19·39	diopside	17
Fe_2O_3	1·94	anorthite	16·40	biotite	20
FeO	4·86	diopside	3·56	calcite	6
MgO	8·08	olivine	4·10		
CaO	8·00	hypersthene	17·96		
Na_2O	2·26	magnetite	2·78		
K_2O	3·68	ilmenite	3·19		
$H_2O +$	2·72	pyrite	1·1		
$H_2O -$	·20	apatite	·67		
CO_2	2·70	calcite	6·1		
TiO_2	1·70				
P_2O_5	·34				
FeS_2	1·10				
MnO	·25				
	99·92				

Symbol "III.5.3.3.
2.2.2.2.

Specific gravity = 2·807 ± ·001 at 4° C.

Although the percentage of modal biotite is here slightly lower than in the minette (No. 47) previously quoted, yet the proportion of normative orthoclase to albite is higher. This rock must therefore be regarded as a minette. It thus seems likely that anorthoclase is capable of a plumose development.

Hornblende-Minette.

By the substitution of hornblende for diopside, the diopside-minettes grade to hornblende-minettes, which, in their turn, grade to hornblende-vogesites by decrease in the amount of biotite.

When hornblende is present in smaller amount than diopside, the latter shows signs of resorption, and the hornblende forms euhedral crystals, seldom longer than 0·4 mm., which sometimes have cores of diopside.

One rock (No. 46 from Horse Island) exhibits large phenocrysts of diopside with biotite developed along the cleavages and, in addition, a little fine hornblende, sometimes with enclosures of diopside, in the matrix. The reaction between diopside and magma which produces hornblende takes place at a later stage than the conversion of diopside to biotite.

As diopside decreases in amount, hornblende increases, until the rocks pass to hornblende-minettes, in which hornblende preponderates over diopside. In these rocks (No. 42 from south of Lady's Port and No. 43 from Ballywaddan are typical) the biotite sometimes has an addition of a bright bluish-green mica on the basal planes, or includes laminae of the same parallel to (001). The green mica is pleochroic with X = yellowish-green, Y = Z = bright bluish-green. Biotite is often enclosed by hornblende. In No. 42, pseudomorphs, possibly after olivine, are rimmed by both biotite and hornblende.

Diopside-Vogesite.

By decrease in the amount of biotite and increase in the amount of diopside, the diopside-minettes grade to diopside-vogesites. This type is rare and the best examples occur on the east coast, north of the Whiskin shore and in the multiple dyke near the Butterlump Stone.

The rock from north of the Whiskin shore (No. 327) is fairly coarse-grained and contains abundant euhedral crystals of diopside, which grade from 1 mm. in length down to 0·06 mm. or less. Anorthoclase, in very irregular grains, averaging about 0·8 mm. in length, is the predominant felspar. Pseudomorphs of chlorite and epidote, which represent biotite, are subsidiary in amount to diopside, and there are rare small euhedral crystals of hornblende. The dyke (No. 325) which outcrops on the shore opposite Black Rock, north of Ballywalter, is of a somewhat similar variety, only it contains diopside and hornblende in equal amounts and the former shows signs of resorption.

The diopside-vogesite (No. 271) near the Butterlump Stone forms a multiple dyke of the symmetrical type. The central intrusion is the coarser in grain and contains abundant euhedral crystals of diopside. The felspar matrix is plumose, and biotite is again replaced by chlorite and epidote. The marginal part has a finer grained plumose felspar matrix, and less abundant, though equally well developed, crystals of diopside, which have a linear arrangement due to flow and sometimes occur in glomeroporphyritic groups.

Pyroxene-Minette Type B.

Pyroxene-minette Type B is distinctly different from that previously described as Type A. In it the monoclinic pyroxene, which differs in character from that in Type A, is more abundant and is the most obvious mineral in a hand specimen. It forms crystals which vary in length from a maximum of 5 mm. down to 0·25 mm., many attaining the larger size. It exhibits a combination of the forms {100} {010} {110} {$\bar{1}$11}, the pinacoids and prism being equally developed, so that transverse sections are almost regular octagons. In thin section it has a scarcely discernible brownish or greenish tint and zoning is apparent, the outer zone sometimes having a slightly stronger colour. The largest crystals have a curious grid structure due to inclusions of the matrix, with which there appears to have been simultaneous crystallization. The inclusions are mainly of felspar together with small pseudomorphs after olivine, small flakes of biotite, stout prisms of apatite, and octahedra of magnetite. There is frequently an inner and outer zone which are free from such inclusions. Simple and polysynthetic twinning parallel to (100) are sometimes shown, and in the latter case the twin laths frequently wedge out in short lengths.

The optical data for the pyroxene are: $Z \wedge c = 46°$, $\alpha = 1{\cdot}686$, $\gamma = 1{\cdot}707$, $\gamma - \alpha = {\cdot}021$ (measured with a graduated quartz wedge), 2V, positive $= 58°$ approximately. The brownish colour, the extinction angle, the refractive indices, and the low double refraction probably indicate that the pyroxene approaches hedenbergite in composition.

Pseudomorphs after olivine are more plentiful than in the minettes of Type A and reach a length of 2 mm. The olivine is replaced sometimes by a single crystal and sometimes by several crystals of what appears to be a ferriferous variety of antigorite. It has a well-marked cleavage and is pleochroic: X = pale yellowish green, Y = Z = pale green. The acute bisectrix X is normal to the cleavage, 2V positive is small and $\gamma - \alpha = {\cdot}015$. The pseudomorphs usually show good form. Occasionally, however, a curved outline is indicative of resorption of the original mineral. They are always surrounded tangentially by biotite flakes. Iron

oxide, although sometimes found as strings within the pseudomorphs, is more often restricted to the margin.

Biotite occurs as small ragged flakes which average only 0·2 mm. in length and do not show the characteristic zoning. It is reddish brown in colour and corresponds with the darker zone of the zoned biotite. Pleochroism is strong: X = pale yellowish, Y = Z = dark reddish brown. This biotite, although plentiful in small flakes, appears to belong to the matrix and is insignificant when compared with the pyroxene phenocrysts or pseudomorphs after olivine.

The accessories are also characteristic of the rock. Apatite forms comparatively broad prisms, reaching a size of 0·3 mm. by 0·25 mm., whilst magnetite is abundant in irregular grains, often measuring 0·3 mm. across.

In the rock from south of the Coast Guard Station and the thicker of the two dykes at Ballyhalbert harbour, the felspar matrix is medium in grain, the average grain size being 0·3 to 0·4 mm., but in the thinner dyke from the harbour the felspar is plumose and the biotite correspondingly finer. In both types the pyroxene and olivine pseudomorphs are equally large and are probably of intratelluric origin.

(iii) Xenoliths and Xenocrysts.

Accidental xenoliths and xenocrysts, derived from the country rocks, are not uncommonly seen in thin section. The former are usually fragments of grit and slate, whilst the latter are always of quartz.

The xenolith of red gneiss, found in a hornblende-minette at the foot of the dunes north of Portavogie Quay, shows distinct gneissic banding of quartz and felspar, and contains garnets, which are often altered to chlorite.

The cognate xenolith from the pyroxene-vogesite at the Whiskin shore is a coarse-grained pyroxene-minette which contains a little hornblende. The hornblende sometimes encloses rounded grains of diopside, and where in contact with such resembles the outgrowths of tremolite and actinolite from the hornblende in vogesite Type B. A small cognate xenolith of a different type was found in a section of the same rock. It measures about 3 mm. across and consists almost entirely of small calcite pseudomorphs after pyroxene and needles of apatite. The pseudomorphs measure less than 0·1 mm. in length. The matrix, which forms only a very small proportion of the xenolith, is felspathic.

5. PETROGENESIS.

The lamprophyre dyke suite of the Ards peninsula is probably genetically related to the Newry igneous complex, and it is worthy of note that the ferro-magnesian minerals present in the dykes

can all be matched in the granite and associated rocks. The unravelling of the exact relationship awaits the more detailed investigation of the Newry complex.

The evolution of all the varieties of rock found in the dykes is not evident. Some attempt can be made, however, to account for the association of hornblende- and pyroxene-biotite-bearing types, on the assumption that the Newry granite was underlaid by a basaltic substratum, differentiation being due to crystal sinking.

The differentiation which produced the granite would bring about an accumulation of olivine and pyroxene in the lower part of the basaltic substratum, and as crystallization proceeded it is not unlikely that hornblende would, in its turn, sink. It has been shown by Bowen [1] that hornblende which enters a basaltic liquid participates in reactions which precipitate, as crystals, earlier members of the reaction series, i.e. olivine, pyroxene, and possibly calcic plagioclase, the constituents of hornblende, other than those precipitated, entering into the liquid. From a study of the norms of ten hornblendites from Washington's *Tables*, he ascertained that the liquid would be enriched in albite and orthoclase. Since nepheline and diopside are capable of forming together a liquid of quite low melting point, he suggests that the nepheline and a nearly equivalent weight of diopside could also enter the liquid, excess of pyroxene being precipitated with the olivine.

In the present case, therefore, the sinking of hornblende crystals and consequent reactions would cause an increase in the amount of olivine and pyroxene present in the basalt, the magma at the same time becoming enriched in alkalies. With continued sinking of hornblende it is to be expected that the crystals of olivine and pyroxene would eventually be attacked by the alkalic magma, and, as already shown, evidence of such a reaction is to be found in the diopside-minettes of the newer series. Olivine is unfailingly rimmed by tangential flakes of biotite, whilst diopside sometimes has biotite developed along its cleavages, aggregates of biotite flakes, with a block-like structure, indicating the former presence of diopside where replacement is complete.

Probably biotite did not always grow in contact with the minerals at whose expense it was formed. The reaction may frequently have consisted of the resorption of diopside and olivine and the deposition of biotite elsewhere. In the rocks which give direct evidence of the development of biotite from diopside and olivine, the remaining diopside is sometimes much resorbed, whilst the olivine-pseudomorphs often have an embayed outline, due to resorption before the biotite rim was formed.

The reason for the conversion of early formed crystals to biotite, in preference to hornblende, is possibly to be found in the proportion of alumina present in the magma. Whatever the cause may be,

[1] N. L. Bowen, *The Evolution of the Igneous Rocks*, p. 270.

Fig 1.

Fig 2.

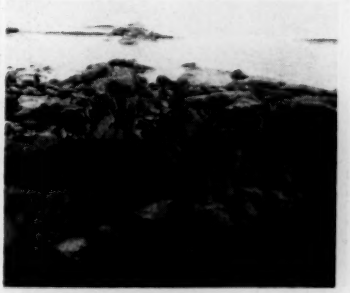
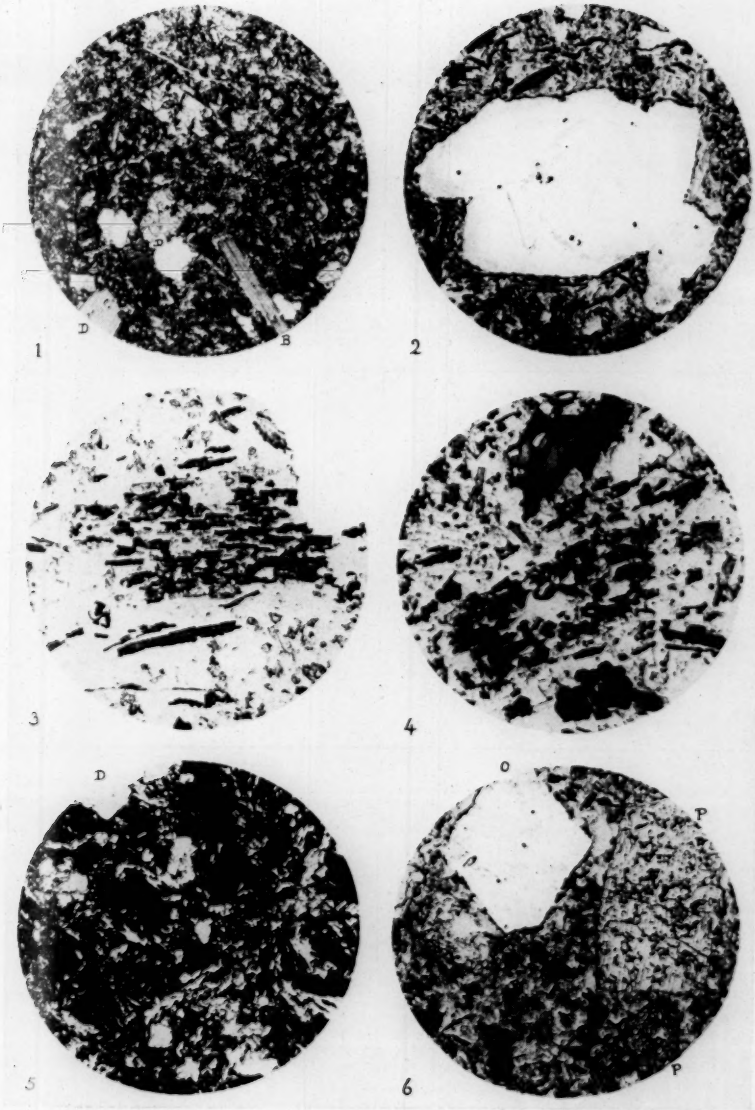


Fig 3.

Fig 4.

MEMBERS OF THE YOUNGER SERIES OF LAMPROPHYRE DYKES, ARDS PENINSULA.

[*To face p.* 160.



PHOTOMICROGRAPHS OF LAMPROPHYRES CHARACTERIZED BY BIOTITE AND PYROXENE, ARDS PENINSULA.

hornblende was formed as a result of such reaction only at a late stage, as is apparent in some of the hornblende-bearing minettes.

The crystallization of pyroxene, or its sinking from higher levels, appears to have continued after the growth of biotite commenced, for in some rocks, in which biotite encloses resorbed grains of diopside, well-formed crystals of the latter also occur, and sometimes partly enclose mica.

If the alkalic magma was the result of the fractional resorption of hornblende by basalt, then the magma was enriched in nepheline. The fact that this felspathoid is not represented in the rocks of the district must be attributed to the liberation of silica due to the early crystallization of olivine and the later large-scale development of biotite.

To explain the association of the two types of rock, one rich in hornblende and the other in biotite and pyroxene, it must be assumed that the basaltic substratum itself became differentiated. There would then result an accumulation of olivine, pyroxene, and, in consequence, of biotite at low levels, the higher levels at the same time becoming saturated with hornblende. With the crystallization of hornblende, any diopside or olivine which still remained at these high levels would be resorbed and hornblende formed in their stead. As evidence of such a reaction the rounded grains of diopside present in some of the hornblende rocks may be cited, in addition to the fact that hornblende sometimes has a core of diopside, whilst the serpentinous pseudomorphs, which possibly represent olivine, are surrounded by small prisms of hornblende. Hornblende sinking from still higher horizons would no longer undergo fractional resorption on entering the upper part of the substratum.

At a later stage, it is likely that alkali-felspars would crystallize in the highest levels of the substratum and undergo a certain amount of gravity-sorting, together with hornblende. At the same time, the base of the level of saturation with hornblende would travel downwards, so that eventually hornblende would crystallize from the higher horizons characterized by biotite and pyroxene.

The variation at different levels, in what was originally a basaltic magma, may at this stage be supposed to be as follows :—

(5) Level characterized by alkali-felspar with a little hornblende.
(4) Level rich in hornblende with some alkali-felspar.
(3) Level rich in hornblende.
(2) Level containing pyroxene, olivine, biotite and hornblende.
(1) Level rich in pyroxene, olivine and biotite.

The residual magma would be rich in alkalies and capable of crystallizing, mainly as anorthoclase and albite, on intrusion.

These suggested levels can be matched by the dyke-rocks in the Ards peninsula, which are listed below in comparable order.

The specify gravity, corrected to 4° C, is given opposite each type, and is consistent with the layering. When the specific gravity has been found for more than one rock of a type all determinations are given and, in addition, their average.

		Specific Gravity at 4° C.	*Average Specific Gravity.*
5.	Felspar-porphyry . .	2·679 ± ·001, 2·661 ± ·001 .	2·67
4.	Hornblende-porphyrite .	2·768 ± ·001, 2·73 . .	2·749
3.	Vogesite type A . .	2·779 ± ·001, 2·785 ± ·002 .	2·782
	Vogesite type B . .	2·835 ± ·001, 2·764 ± ·001, 2·80	2·800
2.	Hornblende-minette .	2·807, 2·837 . . .	2·822
1.	Pyroxene-minette type A	2·819 ± ·003, 2·807 ± ·001 .	2·813
	Pyroxene-minette type B	2·86	2·86

The specific gravity for vogesite type B is very variable. Some of the rocks are rich in large crystals of hornblende, whilst others have fewer and smaller crystals. Possibly this type has been affected by a certain amount of crystal-segregation, during intrusion, owing to obstruction of the dyke-fissure, and perhaps caused by the crystals themselves.

Spessartite *s.g.* = 2·761 ± ·003 has been omitted, since its relation to the other types is not known.

Intrusion was due to rise of the magma, with its crystal load, up the fractures produced by tensional forces. Thus, if the layering indicated is correct, the first dykes to be intruded would contain hornblende and the later ones biotite and pyroxene. This agrees with the order of intrusion found to have taken place in the younger or uncrushed dykes, where pyroxene-minette type B was the last to be intruded.

In the older crushed series hornblende types are very rare and the proportion of ferro-magnesian minerals to felspar is smaller than in the younger series. This is comprehensible when it is considered that the sinking of hornblende into the basaltic substratum and the differentiation of the basalt itself would probably not have gone on to so great an extent, prior to the intrusion of the crushed dykes, as indicated in the case of the younger series. It explains the smaller content of diopside and biotite, the quantity of which is dependent on the fractional resorption of hornblende. The scarcity of hornblende types can be accounted for on the grounds that the upper layers had not yet become saturated with this mineral.

The green glass, which is present in small amounts in the interspaces of the rocks and more particularly in those characterized by hornblende, is of an abnormal type. It contains a large proportion of alumina, which appears in the norms of the rocks as corundum, whilst rocks which contain no glass, or in which glass is present in minute quantities only, have no normative corundum. The glass can therefore be regarded as evidence that an excess of

alumina remained in the residual magma. This is strange considering that the rock analyses show a low percentage of this oxide. Perhaps it may be explained by the fact that the basaltic substratum would have been characterized by a lime-soda felspar, possibly labradorite, if it had crystallized as basalt, whereas the lamprophyres actually contain anorthoclase and albite, felspars less rich in alumina than labradorite. As far as the felspar matrix is concerned, therefore, an excess of alumina is to be expected. Whether it appears or not in residual glass may be dependent on the amount of biotite formed, since biotite is the only ferro-magnesian mineral which contains an excess of alumina over that provided by the partial resorption of hornblende.

Calcite, which replaces quartz and felspar, is characteristic of the younger dykes and more particularly of the pyroxene-biotite type. Since many of these rocks are otherwise fresh, it seems likely that this replacement was a juvenile reaction due to residual solutions charged with carbonates. The existence of such residual solutions may perhaps be connected with the reaction which has been shown to have taken place between diopside and magma, with the consequent production of biotite. Such a reaction must result in an accumulation of lime in the magma, probably greatly in excess of the amount which was able to enter into the composition of the felspar matrix. Any such lime would remain in the residual liquor, together with the volatile constituents, and be likely to be deposited as calcite, as a final stage.

6. SUMMARY OF CONCLUSIONS.

The lamprophyre and allied dykes of the Ards peninsula can be separated into two series in the field. The older dykes, which are crushed and foliated, are confined to the area south of a line from Ringburr to Ringboy Point, whilst the younger series has its greatest development north of this line. In each case the majority of the dykes have an approximate S.W.–N.E. strike parallel to that of the country rocks, and there is a smaller number of dykes which cut these and strike at right angles.

Both series were intruded during periods of tension, which occurred as a reaction to compression. The older series was intruded during a pause in the Caledonian folding, and was subsequently crushed and rendered schistose by continuation of pressure in the original direction. The younger series was intruded at the close of the Caledonian folding.

Members of the crushed series are all lamprophyres and mainly pyroxene-minettes. They are very much decomposed and heavily charged with calcite, largely due to infiltration along the planes of schistosity.

The younger dykes are of two types, one characterized by hornblende and the other by biotite and pyroxene as follows :—

1. Hornblende Type.

Hornblende-porphyrite.
Vogesite.

Type A.—Panidiomorphic texture.
Type B.—Euhedral hornblende in a matrix of anhedral felspar.

Spessartite.
Felspar-porphyry.

2. Biotite-Pyroxene Type.

Pyroxene-minette.

Type A.—Phenocrysts of diopside and biotite and occasional pseudomorphs after olivine in a matrix of anhedral felspar.
Type B.—Phenocrysts of a pyroxene, which possibly approaches hedenbergite in composition, small ragged flakes of biotite and pseudomorphs after olivine in a matrix of anhedral felspar.

Pyroxene-kersantite.
Hornblende-minette.
Diopside-vogesite.

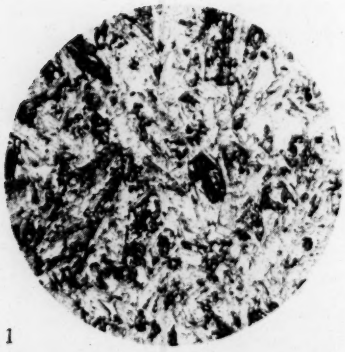
The potash-felspar in both hornblende and biotite-pyroxene types is anorthoclase.

The hornblende dykes, which always strike approximately from south-west to north-east, were the first to be intruded, and are cut by dykes bearing biotite and pyroxene. Dykes of pyroxene-minette type B were the last to be intruded.

The intrusions are probably connected genetically with the Newry igneous complex. The hornblende and biotite-pyroxene types are explained on the assumption that the Newry granite was underlaid by a basaltic substratum enriched by olivine, diopside and hornblende from higher levels. The hornblende would undergo partial resorption, resulting in the precipitation of olivine and diopside, the magma at the same time becoming enriched in alkalies. Reactions between the early-formed crystals of olivine and diopside and the alkalic magma caused the development of biotite.

It is suggested that, as a result of differentiation in the basaltic substratum itself, olivine, diopside and, in consequence, biotite accumulated at lower levels in the substratum, whilst the higher levels gradually became saturated with hornblende, much of which, in addition to some alkali-felspar, crystallized prior to intrusion. The specific gravity of the various types of rock and the order of intrusion is in accordance with such a layering. The residual magma, on intrusion, crystallized mainly as anorthoclase and albite.

As a result of the development of biotite at the expense of diopside, the magma was enriched in lime in excess of the amount capable of entering into the composition of the felspar matrix. Such excess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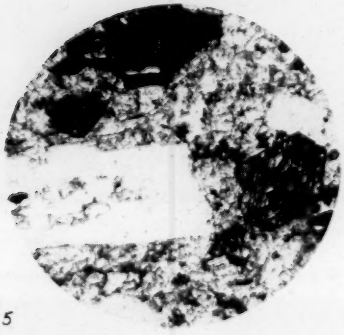
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PHOTOMICROGRAPHS OF LAMPROPHYRES CHARACTERIZED BY HORNBLENDE, ARDS PENINSULA.

To face p. 165.]

remained in the residual liquor, together with the volatile constituents, and was finally deposited as calcite, which has been shown to replace quartz and felspar.

The writer was enabled to undertake this work by the award of the Anonymous Research Studentship at Bedford College in 1928–9.

EXPLANATION OF PLATES VIII–X.

PLATE VIII. MEMBERS OF THE YOUNGER SERIES OF LAMPROPHYRE DYKES, ARDS PENINSULA.

FIG.

1.—Two dykes of vogesite type A (Nos. 236 and 237) at the headland north of Portavogie.

2.—Dykes of vogesite and minette outcropping in the sand north of Portavogie quay.

3.—Coast near the Butterlump Stone, south of Ballyhalbert, showing a diopside-minette (No. 265) intersecting dykes of minette (No. 266) and spessartite (No. 268).

4.—A dyke of diopside-minette (No. 317) intruded parallel to the bedding of the slates at Wallace's Rocks, between Ballyhalbert and Ballywalter.

PLATE IX. PHOTOMICROGRAPHS OF LAMPROPHYRES CHARACTERIZED BY BIOTITE AND PYROXENE, ARDS PENINSULA.

FIG.

1.—Ordinary light, × 14. Diopside-minette type A (No. 276), with a plumose felspar matrix. From near the Butterlump Stone. B = biotite, D = diopside.

2.—Ordinary light, × 14. Diopside-minette (No. 178) from the point north of Bar Hall, showing a group of pseudomorphs after olivine. The group is rimmed tangentially by biotite.

3.—Ordinary light, × 28. Diopside-minette (No. 47), from Horse Island, showing the replacement of a crystal of diopside by biotite. The biotite flakes have been developed along the cleavage in the diopside.

4.—Ordinary light, × 28. Kersantite (No. 233) from the bay south of Portavogie, showing a block-like group of biotite crystals due to complete replacement of diopside.

5.—Crossed nicols, × 28. Diopside-vogesite (No. 271) from near the Butterlump Stone, showing a plumose felspar matrix. D = diopside.

6.—Ordinary light, × 14. Pyroxene-minette type B showing large crystals of pyroxene (P) which probably approaches hedenbergite in composition and a pseudomorph after olivine (O) with a biotite rim. The matrix is of anorthoclase and biotite.

PLATE X. PHOTOMICROGRAPHS OF LAMPROPHYRES CHARACTERIZED BY HORNBLENDE, ARDS PENINSULA.

FIG.

1.—Ordinary light, × 28. Vogesite type A (No. 236) with a panidiomorphic texture. The dark crystals are of hornblende and the interstices between the small felspar laths are occupied by green glass.

2.—Ordinary light, × 28. Vogesite type B (No. 86), showing hornblende crystals in a coarse-grained matrix of anorthoclase and plagioclase.

3.—Ordinary light, × 28. Vogesite type B (No. 269) showing small elongated crystals of hornblende in a coarse-grained matrix of anorthoclase and plagioclase. The pseudomorph is of serpentine probably after olivine and is rimmed by hornblende.

4.—Crossed nicols, × 33. Spessartite (No. 268) showing the trachytic type of matrix. The plagioclase shows flow round the hornblende phenocrysts.

5.—Ordinary light, × 28. Hornblende-porphyrite (No. 213) showing phenocrysts of felspar and hornblende in a matrix of felspar.

6.—Crossed nicols, × 23. Felspar-porphyry (No. 314) showing a glomero-porphyritic group of anorthoclase and plagioclase in a matrix of felspar.

On Composite Lava Flows.

By W. Q. Kennedy, B.Sc.

Introduction.

For many years composite minor intrusions,[1] both sills and dykes, have been known from various parts of the world [2] and most petrologists must have speculated as to the probable effect produced in the event of such composite intrusions having reached the surface in the form of an effusion. For obvious reasons it has not been found possible to trace a composite dyke upwards into a lava flow. However, during the revision of 1 inch Sheet 30 (Renfrewshire) for the Geological Survey, the author encountered, in the neighbourhood of Inverkip, a small village on the Firth of Clyde south of Greenock, certain peculiar lava flows which are believed to represent the effusive equivalents of composite minor intrusions. These "composite lavas", which form the main subject of the present paper, are of Lower Carboniferous age (Calciferous Sandstone Series) and occur interbedded among the more normal flows towards the base of the volcanic group. Two distinct rock varieties, one highly porphyritic, with large phenocrysts (up to 1·5 cms. long) of basic plagioclase, and the other non-porphyritic, are associated within the same flow. The porphyritic type always forms the upper part of the flow and overlies the non-porphyritic; the junction shows unmistakable evidence that both were in a fluid state along their mutual contact at the time of emplacement.

The field relations of the Renfrewshire occurrences are described in some detail below and attention is also directed towards similar composite flows in the Isle of Skye and a possible example on Mount Etna.

A. Renfrewshire.

1. General.

The general geological relations of the area under consideration are shown by the Sketch-map (Fig. 1, p. 168). Petrographically, the Lower Carboniferous lavas, among which the composite flows occur, are similar to those of the Lower Group of North Ayrshire [3] and the Kilpatrick [4] and Campsie Hills.[5] Mugearites, basaltic

[1] The term "composite intrusion" is here used in the sense given to it by Bailey and Thomas in "The Tertiary and Post-Tertiary Geology of Mull, etc.": *Mem. Geol. Surv.*, 1924, 32. See also p. 178 of this paper.

[2] For a general and historical account with references to the older literature, see A. Harker, "The Tertiary Igneous Rocks of Skye": *Mem. Geol. Surv.*, 1904, 197–201.

[3] J. E. Richey, *Trans. Geol. Soc. Glasgow*, xvii, 1927–8, 247–58. J. E. Richey and others in "The Geology of North Ayrshire": *Mem. Geol. Surv.*, 1930, 69.

[4] G. W. Tyrrell, *Trans. Geol. Soc. Glasgow*, xiv, 1912, 219–57.

[5] E. B. Bailey and others in "The Geology of the Glasgow District": *Mem. Geol. Surv.*, 1925, 137–40.

mugearites and highly porphyritic basalts near Markle type [1] are the predominant varieties and are associated with certain transitional types. Olivine-rich lavas are absent. The association of these rock types is of common occurrence throughout the West of Scotland and implies a close community of origin, a fact which has important bearings on the following discussion.

2. Field Relations of the Composite Lavas.

There are four conditions here attached to the definition of a composite lava :—

1. The flow consists of two easily recognizable rock types.
2. The arrangement of the two rock types is asymmetric.
3. The two rock members do not chill against one another, nor is there any intervening slag. The mutual contact is indicative of simultaneous liquidity.
4. The flow is bounded above by a slaggy, vesicular top and below by a slaggy, brecciated base which leaves no doubt as to the effusive nature.

Lavaform bodies which comply with the above definition are well developed on the high ground to the east of the Kip Valley (Sketch-map, p. 168) some two miles north-east of Inverkip. The two uppermost flows which cap Dunrod Hill are of this type : the higher of the two is an outlier but the lower may be traced northward for some distance, the last good exposure being seen in the upper branches of the Spango Glen immediately adjaeent to the aqueduct. Further north the trap featuring has been obliterated and in its absence it is not possible to prove the continuity of the flow. Just below the aqueduct, however, at the locality (A) on the Sketch-map (p. 168), another composite flow is seen, but its relations to the flows further south are unknown. To the east the exposures suggest that composite lavas are also present, but actual contacts are not seen.

The composite nature of these flows is marked by the presence of two distinct rock varieties within the same flow. The lower member in all cases is a fine-grained, non-porphyritic rock of mugearitic affinity and is overlain by a highly porphyritic type in which large phenocrysts of basic plagioclase, up to 1·5 cms. in length but usually about 1 cm., are embedded in a fine-grained groundmass indistinguishable from the lower rock. No chilled contact or intermediate layer of slag separates the two types, and the lower non-porphyritic rock is in perfect continuity with the groundmass of the upper. Although for convenience we may speak of the

[1] In the Markle type of basalt, macro-phenocrysts of labradorite-bytownite up to 1·5 cms. long are set in a groundmass of acid labradorite, augite, subordinate olivine, and magnetite. For definitions and a general discussion of the Carboniferous olivine-basalts and mugearites, see A. G. MacGregor, *Trans. Geol. Soc. Glasgow*, xviii, 1928, 324–60.

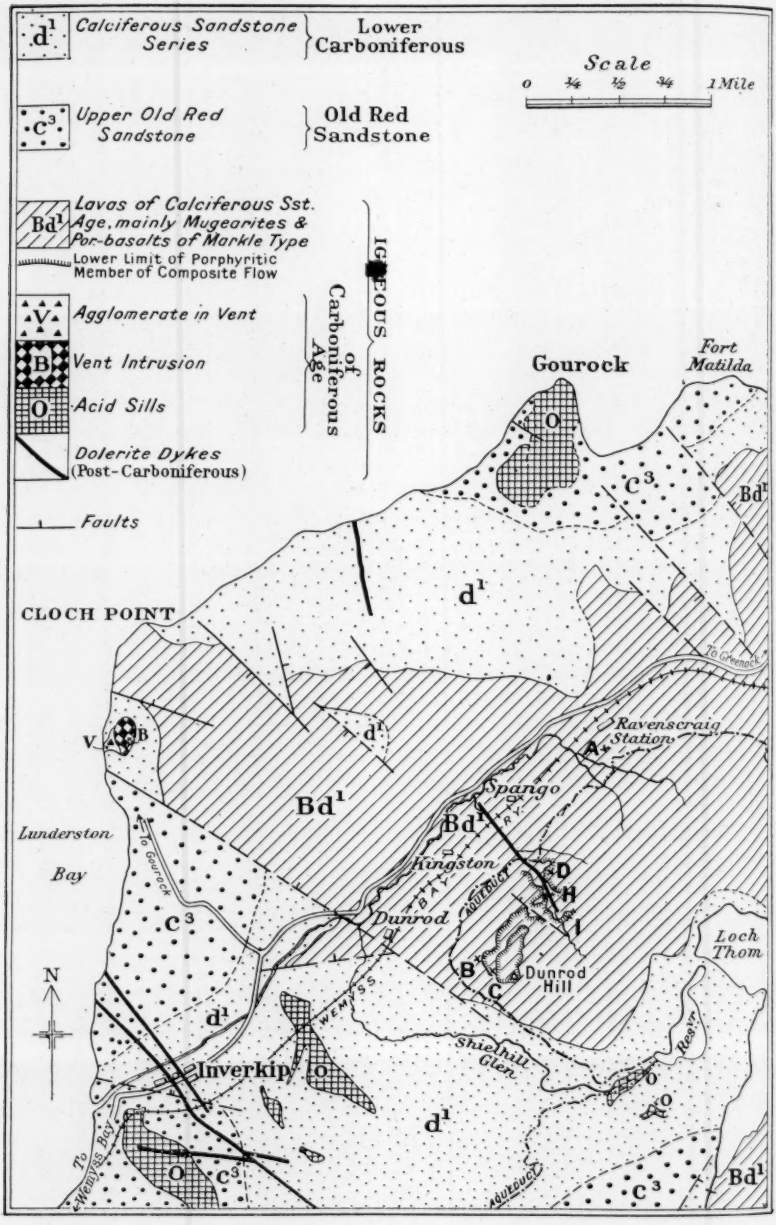

FIG. 1.—Geological sketch-map of the neighbourhood of Dunrod Hill, Renfrewshire. Dykes mostly omitted.

junction between the members, it must be remembered that the line of separation is marked only by the lower limit of the phenocrysts. Mingling of the two magmas has taken place to some extent along the mutual contact and attests to the simultaneous fluidity at the time of emplacement, for large isolated phenocrysts of plagioclase have sunk from the upper porphyritic basalt into the topmost six or eight inches of the lower non-porphyritic rock. These sunken phenocrysts, or more correctly, xenocrysts, have an anorthite content of 70 per cent, identical with that of the phenocrysts of the upper member, whereas the small, sparse porphyritic felspars occasionally found throughout the lower portion of the composite flow are never more basic than 55 per cent anorthite.

Criteria of Effusive Nature.—That the rocks described are flows and not sills is clearly shown by the fact that their solid centres, which make the strong features, are seen to pass upwards into a rotted, slaggy, scoriaceous top and downwards into a narrower slaggy and brecciated base. The transition from solid centre to slaggy base and top is gradual and the possibility of the centre being intrusive into slag could not be entertained.

Good sections of the base of a composite flow are seen in the branches of the Spango Glen immediately below the aqueduct (locality (D) on Sketch-map, p. 168). The basal slag of the composite flow rests on the rotted top of an underlying mugearite and consists in part of sub-rounded blocks of vesicular lava which cannot have formed by brecciation in situ but must represent portions of the original crust which slipped down and were overridden by the advancing front of the lava stream. It is of importance that the basal brecciated layer was found to contain no porphyritic lava, although careful search was made. This downslipping effect is the normal condition of extrusion and evidence of it is everywhere abundant. The upper porphyritic layer, as seen best on the hillside above Ravenscraig Station, passes gradually upwards into a scoriaceous, amygdaloidal top which contains many felspar phenocrysts and is overlain by the base of the succeeding lava. This attests both to the intratelluric origin of the phenocrysts and the asymmetric form of the composite body.

Variation in Thickness of members.—When traced over an area the relative thickness of the two members may vary. Increase in thickness of the upper at the expense of the lower leads to the total elimination of the latter and vice versa. Lateral dying out of the porphyritic upper layer is seen on Dunrod Hill and affects the second flow below the summit. At locality (B) on the Sketch-map (Fig. 1, p. 168) the junction of the associated rock types is visible in the scarp at about eye level. When traced to the south, however, it is seen to cut diagonally across the strike and at locality (C) the porphyritic rock disappears completely, the flow continuing as a simple non-porphyritic sheet. The actual termination of the upper member is exposed and interfingering of

the types occurs. The reverse case is also known but cannot be so completely demonstrated. At locality (H) a composite junction is exposed. The approximate base of the upper porphyritic rock can be traced south-east along the hillside and finally crosses a small burn. In the burn (I), however, the porphyritic rock rests with a slaggy base on top of a mugearite which is definitely known to underlie the entire composite flow. The upper member has here travelled beyond any point reached by the non-porphyritic rock and the latter has been cut out in consequence of this overlap so that the porphyritic type continues beyond as a simple homogeneous flow.

3. Petrography.

Both rock types are of very uniform character, and material from the various flows differs, as a rule, only in the relative degree of freshness, so that descriptions of the analysed specimens will serve to illustrate the nature of the rocks as a whole.

Non-porphyritic type (basaltic mugearite).—These rocks are very dense and aphanitic, almost totally non-porphyritic except for a few widely scattered, small (> 2 mm.) microphenocrysts of plagioclase. A well-marked platy appearance is characteristic and results from a parallel orientation of the small felspar laths which make up the bulk of the rock. Pale buff weathering tints are quite common, but more often are obscured by reddish-brown staining with iron oxide.

The rare, small, zoned microphenocrysts of plagioclase are of labradorite, which is never more basic than An 55 per cent. They are surrounded by a narrow, well defined, and highly zoned outer rim of more acid composition which varies from andesine to oligoclase (An 28–30 per cent) and presents a ragged edge to the groundmass into which it appears to merge. A few small microphenocrysts of pale fawn augite may also be seen. The bulk of the rock has a trachytic texture and consists predominantly of slender laths (·15–·2 mm. long) of andesine, numerous small grains and prisms of pale augite, subordinate olivine and rather abundant iron ore and apatite. The felspar laths show good flow structure (parallel orientation) and wrap round the sparse phenocrysts. They are themselves zoned and vary from andesine (An 40–45 per cent) in the centre to oligoclase at the margins. The boundaries of the laths are serrate and the acid mantles are occasionally seen to be in continuity with an obscure felspathic residuum which fills the interspaces and is referred to oligoclase; some, however, may be orthoclase. The augite is fresh and tends to occur in part in small granular patches in which the little prisms form strings with a radial arrangement. Olivine is subordinate in amount to augite and is seldom fresh. The small idiomorphic crystals are represented by pseudomorphs in chlorite and iron ore, or occasionally

granular silica. A characteristic feature of the rocks is their high content of iron ore, mostly magnetite. Some of this is of secondary origin, but the greater part is undoubtedly an original constituent. Some shreds of biotite and brown hornblende are distributed through the rock and apatite is fairly abundant in long slender needles. Small amounts of residual analcite may be detected with high power objectives. The faint reddish colouration must result from hematite dust, but this is not conspicuous in the slice. This rock has been analysed and the result is set out in Table I (p. 171), No. 1. For comparison are quoted analyses of a mugearite from Rum (A) and an andesine-andesite from the Hawaiian Islands (B).

TABLE I.

	A.	I.	B.	C.	2.	D.
SiO_2	50·70	48·40	49·73	45·62	47·71	49·01
Al_2O_3	14·60	16·66	16·39	18·17	18·09	16·29
Fe_2O_3	5·23	8·54	7·53	1·28	8·57	7·61
FeO	7·68	2·85	3·98	8·30	2·61	4·89
MgO	4·15	4·85	4·06	6·48	4·45	3·62
MnO	0·42	–	0·23	0·35	–	0·27
CaO	7·20	7·44	7·17	9·43	8·52	9·79
Na_2O	3·71	3·42	4·12	4·22	3·58	3·82
K_2O	1·33	1·76	1·93	1·43	1·68	0·80
H_2O +	1·15	1·19	0·54	1·54	1·12	–
H_2O –	2·08	1·23	0·81	0·47	1·00	–
TiO_2	1·89	3·06	3·05	2·09	2·52	3·93
P_2O_5	0·49	0·49	0·84	0·71	0·41	0·49
CO_2	–	tr.	–	–	tr.	–
FeS_2	–	0·07	–	–	0·07	–
LiO_2	tr.	tr.	–	–	tr.	–
Rest	0·08	–	0·06	–	–	0·32
Total	100·71	99·96	100·58	100·09	100·33	100·84

A. Mugearite, south base of Fionn-Chro, Rum, anal. W. Pollard, quoted from A. Harker, "Geology of the Small Isles, etc.": *Mem. Geol. Surv.*, 1908, 130. "Rest" includes NiO tr., BaO 0·08, SrO tr.

1. Basaltic mugearite, lower member of composite lava flow, west scarp, Dunrod Hill, near Inverkip, Renfrewshire, anal. B. E. Dixon.

B. Andesine-andesite, elevation 11,000 feet, south-east slope, Mauna Kea, Hawaiian Islands, anal. Steiger, quoted from H. S. Washington, *Am. Jour. Sci.*, v, 490, table V, No. 3. "Rest" includes ZrO_2 0·03, BaO 0·03.

C. Olivine-basalt (Markle type) ? intrusion. Auchineden Hill, Kilpatrick Hills, Dumbartonshire, anal. A. Scott, quoted from Tyrrell, *Trans Geol. Soc. Glasgow*, xiv, 1913, 244.

2. Labradorite-phyric basalt (near Markle type), Upper member of composite lava flow, west scarp, Dunrod Hill, near Inverkip, Renfrewshire, anal. B. E. Dixon.

D. "Porphyritic basalt," Kohala, anal. Lyons; quoted from H. S. Washington, *Am. Jour. Sci.*, v, 1923, 483. Includes 0·02 S, 0·10 Cu. 0·20 SO_3. Ignited before analysis.

These three rocks closely resemble one another both chemically and modally. The mugearite from Rum, according to Harker, occupies a position intermediate between the mugearites proper and the dolerites, but its petrographical characters link it decidedly to

the former.[1] The Hawaiian rock likewise forms a transition between the olivine-oligoclase-andesites (true mugearites) and the aphyric basalts of the region.[2] The mugearite from Rum is slightly poorer in alumina than the other two and the Hawaiian rock is a little richer in alkalis. The ferric and ferrous iron varies somewhat and in all cases Fe_2O_3 tends to be high; the abnormal richness in the case of the basaltic mugearite may be ascribed, in part, to slight oxidation of the iron ores: total iron is about the same in all three. The chemical similarity is more clearly seen when we compare the Niggli values:—

NIGGLI VALUES.

	si.	al.	fm.	c.	alk.	k.	mg.
B. Andesine-andesite .	133	26	40	20·5	13·5	·23	·40
A. Mugearite . .	132	23	45	20·5	11·5	·19	·37
I. Basaltic mugearite	125	25·5	42	21·0	11·5	·25	·45

The only striking point of difference lies in the higher *alk.* value for the andesine-andesite. The three rocks are obviously to be referred to one type and the "essexite-gabbro" chemistry is very marked.

Porphyritic type (labradorite-phyric basalt near Markle type [3]).—This is a conspicuously porphyritic rock with many large plagioclase phenocrysts, up to about 1 cm. in diameter, but with occasional individuals twice this size, set in a densely aphanitic, dark grey or slightly reddish groundmass. A platy appearance is visible only in the immediate vicinity of the composite junction.

The large porphyritic crystals are of labradorite-bytownite (An 70 per cent). Zoning is ill-defined in the interiors of the crystals, but there is almost invariably a narrow, well-marked and highly zoned outer mantle which varies from acid labradorite or andesine to oligoclase at the extreme margin and merges into the groundmass in a manner similar to that described for the basaltic mugearites. Numerous smaller crystals are commonly present and these may have a slightly more acid composition. Occasional large idiomorphic crystals of pale fawn augite are present in some of the slices. The groundmass closely resembles the non-porphyritic rock except that a parallel orientation of the small andesine laths is not pronounced, the texture being more basaltic. There is, however, a tangential arrangement of the laths around the phenocrysts. The groundmass felspar is andesine of composition An 40–45 per cent. The laths are themselves zoned and are oligoclase at the margins.

[1] A. Harker, "Geology of the Small Isles, etc.": *Mem. Geol. Surv.*, 1908, 131.

[2] H. S. Washington, "Petrology of the Hawaiian Islands": I. Kohala and Mauna Kea: *Am. Jour. Sci.*, v, 1923.

[3] This rock being a transitional type does not fit readily into the classification. It is, strictly speaking, a basaltic mugearite with the addition of large phenocysts of basic plagioclase but has been named basalt, as it seemed inadvisable to extend the term "mugearite" to include a rock so rich in phenocrysts of basic plagioclase. It might, however, be termed *labradorite-phyric basaltic mugearite.*

Augite is abundant in small, idiomorphic grains which tend to become aggregated into little glomeroporphyritic groups. These are sometimes seen to surround a central xenocryst of quartz. Olivine is subordinate in amount to augite but forms slightly larger grains which are rarely fresh and are usually represented by pseudomorphs in iron ore and chlorite. Iron ores are prominent and together with apatite and small amounts of felspathic residuum constitute the remainder of the rock. Small shreds of biotite and brown hornblende are subordinate but constant accessories. The analysis of this rock is given in Table I (p. 171), No. 2. It differs from that of the basaltic mugearite (No. 1) mainly in the higher lime and alumina due to the presence of phenocrysts of basic plagioclase, otherwise both analyses are very similar. For comparison are given analyses of a Markle basalt from the Kilpatrick Hills (C) and a felspar-phyric basalt from Kohala (D). The Markle basalt shows the same high alumina, but at the same time is richer in lime. The Hawaiian rock also shows high lime, but does not contain so much alumina as either of the Scottish basalts. These characters are clearly expressed by the Niggli values :—

	si.	al.	fm.	c.	alk.	k.	mg.
Felspar-phyric basalt, Hawaii (D	122	24	38·5	26·5	11	·13	·35
Labradorite-phyric basalt (I) .	121	27	39	23	11	·24	·43
Markle basalt (C) . . .	104	24·5	41	23	11·5	·18	·54

The Renfrewshire rock occupies a position intermediate between the Markle basalt and the Hawaiian lava. The latter is characterized modally by phenocrysts of basic plagioclase associated with andesine as the groundmass felspar. The differences between the three analyses may be explained, in part, as due to the tendency, among porphyritic rocks, to depart from a mean composition, in a much greater degree than aphyric varieties.

4. Differentiation and Mode of Origin.

The problem now arises as to whether the separation into two layers took place before or after extrusion. The possibility of gravitative differentiation in situ involving relative movement of suspended crystals and liquid cannot be dismissed without consideration, as some investigators have invoked this process to explain marked differences in composition between various parts of the same flow. In a massive flow of obsidian described by von Buch from Teneriffe, the upper portion contained only sparse phenocrysts of felspar (? alkali felspar) whereas the basal layers were so crowded with phenocrysts as to resemble a "*primary rock*".[1] An analogous case is a basalt lava from James Island in the Galapagos Archipelago[2] in which the basal part is crowded with porphyritic

[1] Leopold von Buch, *Physicalische Beschreibung der Canarischen Inseln*, Berlin, 1825, 229.

[2] Charles Darwin, *Geological Observations*, 2nd ed., 1875, 132.

plagioclase crystals whereas only sparse phenocrysts are present above. Darwin, who described this latter example, regarded both cases as clear evidence of gravitative sinking of the phenocrysts subsequent to extrusion.[1]

The difficulties in the way of such an explanation for the Renfrewshire type of flow are, however, almost insuperable. The complete separation into porphyritic and non-porphyritic portions could scarcely have been accomplished in the limited time available before cooling and viscosity put a stop to all movement of crystals. Moreover, it would have been necessary for the phenocrysts to have moved upwards. Had movement been possible, however, the crystals should have sunk as they have a higher sp. gr. than the groundmass and when the latter was fluid this must have been more marked. Finally it has been shown that movement of the phenocrysts did occur to a limited extent (p. 169) and the movement was downwards as one would expect. This sinking of plagioclase from the upper into the lower layer is alone sufficient to disprove differentiation in situ as the controlling factor in the origin of these composite lavas.

The two magmas which gave rise to the porphyritic and non-porphyritic rock-types must therefore have undergone differentiation prior to extrusion and have existed as separate bodies within the magma basin. The nature of the field relations indicate, as in the case of composite minor intrusions, that the two types of magma must have become available at about the same time.[2] Thus the effusion commenced with outflow of one type of magma and finished with the second, the change from one to the other having taken place sometime during the act of extrusion. Both field evidence and comparison with composite dykes of similar constitution indicate that the non-porphyritic type preceded the porphyritic and did not penetrate along the base of the latter in the manner of auto-injection. The asymmetric form of the composite flow as a whole, the gradual downward passage of the lower mugearite into a basal slag free from all phenocrysts of plagioclase and the slight sinking of porphyritic crystals along the junction of the two members is sufficient evidence to preclude the possibility of intrusion of the mugearite along the base of the upper porphyritic rock.

Certain peculiar composite dykes, in which both rocks are of basic composition, are described by Harker from Skye.[3] They are bilaterally symmetrical, consisting of a central porphyritic member flanked on either side by non-porphyritic margins against which the central member fails to chill. Harker says :—

[1] Op. cit., 132–3.

[2] E. B. Bailey and H. H. Thomas, "The Tertiary and Post-Tertiary Geology of Mull, etc." : *Mem. Geol. Surv.*, 1924, 33.

[3] A. Harker, "The Tertiary Igneous Rocks of Skye" : *Mem. Geol. Surv.*, 1904, 298.

"There is no such sharp line of demarcation as would exist had the marginal and central portions been intruded at quite different epochs. It is not possible, however, to account for the variation by differentiation in situ after the intrusion . . . . . there was a first intrusion represented by the margins of the dyke, and, before that had consolidated in the interior part, a second intrusion, now represented by the central band of the dyke."

During the act of intrusion the magma flowing in the fissure suffered change of composition and the liquid centre of the dyke was eviscerated by inflow of later porphyritic magma.[1]

Similar composite dykes of Carboniferous age have been mapped by Mr. A. G. MacGregor and the author in Renfrewshire, but are too decomposed to allow of determination of the rock-types. A fresh example occurs, however, on the Great Cumbrae in the Firth of Clyde. A central, highly porphyritic band consisting of basalt of Markle type is flanked on either side by non-porphyritic margins of Jedburgh type of basalt.[2] This association is significant, as the Jedburgh type may be regarded as the basic end of the mugearite series. Had this dyke reached the surface it must have resulted in a composite flow almost identical with those at Inverkip. The evidence is, therefore, in all the cases mentioned, that the porphyritic magma followed the non-porphyritic.

Mode of Emplacement.—When a viscous liquid flows over a rough surface the effect of friction causes retardation of the basal portion. Differential movement is set up so that the upper part of the stream flows more rapidly. A good example is afforded by a glacier flowing in a valley. The base and sides are retarded by contact with the floor and walls of the valley, so that the most rapid movement takes place in the centre. In the case of a lava, cooling along the contact with the underlying rocks will increase the retardation of the base and so the faster moving upper portion will constantly tend to overlap the basal parts. The total effect is therefore to transfer magma from the rear (that is magma which was extruded later) towards the front of the flow across the more slowly moving lower part of the stream. This must take place in any extrusion, but only when the later magma shows some easily recognizable difference in composition will it become apparent. In the Renfrewshire flows the porphyritic magma only became available after the effusion had been proceeding for some time. By the operation of the conditions outlined above this porphyritic material would tend to be transferred, as a fast moving upper layer, towards the front of the flow. In this manner porphyritic material would be brought to overlie the slower

[1] Unfortunately there exists at present no suitable term for a magma containing suspended crystals which under conditions of rapid cooling would give rise to a coarsely porphyritic rock. The term "porphyritic magma" is here used to designate such a type.

[2] G. W. Tyrrell, "Geology of the Cumbrae Islands": *Trans. Geol. Soc. Glasgow*, xvi, 253.

moving non-porphyritic basal portion. The junction between the two parts would be liquid and no chilling of the contact or development of an intermediate layer of slag would be possible.

Providing that the velocity of flow and strength of frictional retardation were suitable, the later porphyritic magma might overlap the non-porphyritic part completely and continue as a simple porphyritic flow. On the other hand the porphyritic upper portion might not reach the front of the flow before consolidation of the lava, in which case the composite body would continue beyond a certain point as a simple, homogeneous, non-porphyritic lava. As has been shown above, both of these cases have been recognized among the composite lavas of Renfrewshire.

B. OTHER OCCURRENCES OF COMPOSITE LAVAS.

1. Skye.

Tyrrell appears to have been the first to point out that the Markle basalt-mugearite association of the Scottish Carboniferous province has a Tertiary analogue in the Roineval type of composite sheet in Skye. He says [1]:—

"In Skye mugearites form composite sills along with a highly porphyritic type of olivine-dolerite. This association is interesting in view of their occurrence in the Carboniferous rocks associated especially with porphyritic lavas of Markle type."

This statement becomes additionally significant when we consider the presence, in Renfrewshire, of composite lavas in which basaltic mugearite and porphyritic basalt form the associated rocks.

The Roineval sills of Skye form a small group comprising some eight individual members known from three localities: Roineval, two miles N. of Drynoch; Druim na Criche, five miles S.W. of Portree; and Dun Hill, two miles N. 15° W. of Talisker.[2] The first two localities were examined by the author, who was, however, unable to visit the Dun Hill. The following account is based on personal field examination, and it is in almost complete agreement with the observations recorded by Harker.

The bodies are asymmetric in form and show a lower layer of mugearite, devoid of phenocrysts, overlain by a highly porphyritic olivine-dolerite or basalt containing many large phenocrysts of labradorite. There is no sharp line of demarcation between the two members and, as in Renfrewshire, large isolated phenocrysts have sunk from the upper member into the topmost six inches of the mugearite.[3] Typically, the groundmass of the porphyritic member is distinctly coarser in texture than the mugearite. However, this

[1] G. W. Tyrrell, *Trans. Geol. Soc. Glasgow*, xiv, 1912, 226.

[2] A. Harker, "The Tertiary Igneous Rocks of Skye": *Mem. Geol. Surv.*, 1904, 256–70.

[3] This was found to be the case at Druim na Criche as well as at Roineval, and the phenomenon is not confined to the latter locality, as stated by Harker. See A. Harker, op. cit., 256.

groundmass is in perfect continuity with the mugearite below and there is a gradual transition from one to the other both as regards texture and composition.

Apart altogether from their intimate field relations, the two rock types have certain characters in common which serve to link them together. Harker [1] points out that the difference in composition between the mugearite and the *groundmass* of the porphyritic rock is slight and much less than the difference between the bulk analyses of the two rocks. The analyses are given in Table II (p. 177), Nos. 1 and 2.

TABLE II.

	1.	2.	3.	4.	5.
SiO_2	50·33	49·24	49·26	48·48	46·45
Al_2O_3	19·97	15·84	21·42	15·92	16·98
Fe_2O_3	2·81	6·09	4·06	3·42	3·94
FeO	6·23	7·18	4·78	8·00	8·57
MgO	3·24	3·02	2·02	5·05	5·94
CaO	8·03	5·26	8·60	10·09	7·64
Na_2O	4·30	5·21	4·40	4·13	3·50
K_2O	1·19	2·10	1·40	1·61	1·48
H_2O+	0·99	1·61	1·07	0·01	1·68
H_2O-	0·87	1·08	0·72	0·03	0·24
TiO_2	1·81	1·84	1·22	2·03	3·11
P_2O_5	0·17	1·47	0·98	0·65	0·51
MnO	0·17	0·29	0·19	0·18	0·48
Rest	0·06	0·30	—	0·13	0·47
Total	100·17	100·46	100·2	99·81	100·94

1. Porphyritic olivine-dolerite; upper member of composite sheet, Druim na Criche, Skye. Anal. W. Pollard. Quoted from A. Harker, "The Tertiary Igneous Rocks of Skye": *Mem. Geol. Surv.*, 1904, 263. "Rest" includes CrO_2 tr., (NiCo)O tr., BaO 0·06, SrO tr.
2. Mugearite; lower member of same body. Anal. W. Pollard. Op cit., 263. Includes CrO_2 tr., (NiCo)O tr., BaO 0·09, SrO tr., F 0·18, S 0·03.
3. Calculated composition of a rock consisting of one-third labradorite (Ab_1An_3) phenocrysts in a groundmass of mugearite composition.
4. Andesine-basalt; Lava of 1910, above Nicolosi, Etna. Anal. Washington. Quoted from the *Am. Jour. Sci.*, xii, 1926, 404. Includes BaO 0·09, SO_3 0·14.
5. Olivine-basalt (Jedburgh type); Plug, Little Caldon neck, north of Kilpatrick Hills, Stirlingshire. Anal. E. G. Radley. Quoted from "The Geology of the Glasgow District": *Mem. Geol. Surv.*, 2nd ed., 1925, 182. Includes CO_2 0·41, Fe_7S_8 0·06.

The silica percentage is about the same in both the mugearite and the olivine-dolerite, but the porphyritic rock is richer in alumina and lime and slightly poorer in alkalis. This difference in composition obviously results mainly from the presence of labradorite phenocrysts in one of the rocks. Plagioclase phenocrysts constitute roughly about one-third of the porphyritic member and it is possible to calculate the composition of the rock produced by adding labradorite

[1] A. Harker, "The Tertiary Igneous Rocks of Skye": *Mem. Geol. Surv.*, 1904, 259 and 263.

phenocrysts of composition Ab_1An_3 to the mugearite in this proportion. The calculated analysis (Table II, No. 3) is very similar to the porphyritic dolerite (I); the magnesia, however, is low, but this is natural as the olivine-dolerite is slightly richer in augite than the mugearite. Comparison of the Niggli values shows that the variation between the associated rocks from Skye is in the same direction as, but is slightly greater than, between the members of the Renfrewshire composite lava. In both cases the rocks are of the same general composition, but those from Skye are distinctly richer in alkalis.

	si.	al.	fm.	c.	alk.	k.	mg.	
Porphyritic dolerite.	140	31	33	23	13	·18	·39	Skye.
Mugearite . .	135	25·5	42	15·5	17	·21	·30	Skye.
Porphyritic basalt .	121	27	39	23	11	·24	·43	Renfrewshire.
Basaltic mugearite .	125	25·5	42	21	11·5	·25	·45	Renfrewshire.

Thus in their petrographical character as well as in their field relations the Roineval sheets bear a close resemblance to the composite lavas of Renfrewshire. The latter are, however, undoubtedly effusive rocks, whereas Harker regarded the Skye occurrences as intrusive sills. It must be remarked that he gives no field evidence in support of this conclusion, and his interpretation of the Roineval sills appears to be based on their composite nature and on the fact that they occur interbedded among the basalt lavas, producing strong features (trap featuring) in a manner similar to the "great group of basic sills" with which they are linked in time.[1] Later workers in the Hebridean province have, however, presented convincing evidence that the so-called basic sills of the "great group" are merely the solid centres of lava flows,[2] and this would seem to apply also to the Roineval type of composite sheet.

At Roineval itself only one composite sheet, repeated by faulting on the east, appears to be present. The lower mugearite of this body may be traced downwards, becoming gradually vesicular until finally it rests with a slaggy, brecciated base free from all porphyritic material, upon the weathered vesicular top of an underlying flow of mugearite. The base is unquestionably that of a lava. At Druim na Criche several composite sheets are found one above the other. The scarps, in which the composite nature is seen, are separated by peaty flats the gradual transition from solid centre to slaggy top and bottom being again evident.

Certain theoretical considerations also have a direct bearing upon the extrusive origin of asymmetric composite sheets such as those of Skye and Renfrewshire. Composite minor intrusions, in the

[1] A Harker, "The Tertiary Igneous Rocks of Skye": *Mem. Geol. Surv.*, 1904, 269. A. Harker, "The Geology of the Small Isles, etc.": *Mem. Geol. Surv.*, 1908, 129.

[2] E. B. Bailey, "The Sgùrr of Eigg": GEOL. MAG., 1914, 303. E. B. Bailey and others, "The Tertiary and Post-Tertiary Geology of Mull, etc.": *Mem. Geol. Surv.*, 1924, 95–6.

redefined sense of Bailey and Thomas,[1] are characterized by bilateral symmetry, a central portion being flanked on either side by marginal parts which differ from it in composition. In the Hebridean Tertiary province it is most common to find a central granophyre flanked by basalt. Departures from this typical bilateral symmetry are known but, as shown by Harker, such departures are accidental and result from the destruction of one of the flanking basalts by the granophyre magma.

Bilateral symmetry and failure of the component members to chill against one another are natural and inevitable results of the mode of formation. The composite relations result from evisceration of the still liquid centre of a basic intrusion by slightly later inflow of acid magma. In both sills and dykes cooling and solidification commence at the margins and spread inwards towards the centre. This interior part will remain fluid and permit active flow of magma long after the margins are solid. If the later magma flowing in the centre of the intrusion now suffers a change in composition from basic to acid, this acid magma will sweep on the basic and come to occupy its position. The intrusion will therefore consist of an acid centre flanked by basic margins against which it does not chill. In order to produce an asymmetric intrusion it would be necessary to postulate that the magma first intruded commenced to cool and solidify *on one side only* while the other remained liquid down to the actual contact against the country-rock. Complete evisceration of the liquid portion would then give rise to an asymmetric composite sill. It is highly improbable, if not totally impossible, that such conditions could ever be realized in nature, and the possibility of the development of an asymmetric composite intrusion is therefore very slight. On the other hand, as shown above, asymmetry would be the natural result if the " composite magma " reached the surface as an effusion and, this being the case, asymmetry may almost be regarded as one of the criteria of extrusive nature in a composite body.[2]

Thus in view of the field evidence, supported by the theoretical considerations outlined above, it is not possible to accept any conclusion other than that the Roineval type of composite body in Skye is of true extrusive origin and represents the Tertiary equivalent of the composite lavas of Renfrewshire.

[1] There are three conditions attached to the new definition : (1) Composite intrusions are composed of parts of recognizably different composition ; (2) As a complex they chill exteriorly against country-rock ; (3) The component parts do not chill against one another—if they do the intrusion is *multiple*, not composite. See E. B. Bailey and H. H. Thomas, in " The Tertiary and Post-Tertiary Geology of Mull, etc." : *Mem. Geol. Surv.*, 1924, 32.

[2] This asymmetry resulting from composite extrusion must not be confused with that produced in an intrusive sheet by gravitative differentiation in situ such as in the peculiar differentiated sill described by Iddings from Electric Peak, Montana. See J. P. Iddings and others in " The Geology of the Yellowstone National Park " : *Monograph* 32, *U.S.G.S.*, **2**, 1899, 82–4.

2. Mount Etna.

From the scanty data at present available, it appears highly probable that the 1910 flow of Etna is a composite lava similar in type to those described from Renfrewshire and the Isle of Skye.

In a recent paper Washington has made a valuable contribution to our knowledge of the chemical and petrographical characters of the Etnean lavas.[1] A most significant fact which he recognizes is that "different parts of the same flow, such as that of 1910, may exhibit different varieties".[2] The main (lower) portion of this flow consists of andesine-basalt. The rock is dark grey with many small (1–2 mm.), inconspicuous tables of felspar, but few or none of augite and olivine, in a dense aphanitic groundmass. The abundant felspar microphenocrysts are labradorite (Ab_1An_1). The groundmass is fine-grained and almost opaque with many small laths of andesine (Ab_3An_2) scattered through it. Under high powers the darker groundmass is found to consist of an aggregate of small grains of augite and magnetite with, sometimes, a little glass. The upper part of the flow is of quite different character. Washington says[3]:— "What may be a distinct variety is found in the vesicular, upper parts of the flow of 1910. This shows rather many and fairly large, up to 5 mm long, phenocrysts of andesine and some of black augite in a medium grey aphanitic groundmass. The thin sections closely resemble those of other specimens from the same flow. This variety may indicate a different set of conditions of crystallization in the upper part of the flow, or else the rising of the larger felspar crystals through the liquid."

The microporphyritic rock is an andesine-basalt according to Washington's classification, but both modally and chemically it is not very different from the Jedburgh type of basalt in the Scottish Carboniferous. Such Jedburgh basalts are related to the mugearites and are common associates of porphyritic lavas of Markle type. Comparison of the analyses, 4 and 5 in Table II, bring out the resemblance in composition. There is, unfortunately, no analysis of the macroporphyritic variety from Etna, but it cannot differ very greatly in composition from felspar-phyric basalts such as those from Scotland and Hawaii.

The 1910 flow of Etna thus presents the phenomenon already described from Scotland, namely, a lavaform body which shows a lower portion devoid of macrophenocrysts and an upper part containing many large crystals of plagioclase in a groundmass similar to the underlying rock. An origin similar to that of the composite lavas of Renfrewshire and Skye is probable, but without a careful and detailed field examination this interpretation must remain but a hypothesis.

[1] H. S. Washington, M. Aurousseau, and Mary G. Keyes, "The Lavas of Etna": *Am. Jour. Sci.*, xii, 1926, 371–408.
[2] Op. cit., 398.
[3] Op. cit., 401.

A fact which cannot be overlooked is that, in all three cases, in Renfrewshire, in Skye, and at Etna, the composite lavas consist of rocks of the same general type. Mugearitic lavas, in which low silica combined with low lime and rather high alkalis lead to the presence of andesine, are associated with highly felspar-phyric basalts of related composition. This association is not confined to composite bodies, but wherever mugearites (olivine-oligoclase-andesites), basaltic mugearites (andesine-andesites) and related non-porphyritic rocks occur, highly felspar-phyric basalts are also present. Such is the case in Scotland, the Hawaiian Islands, Italy, and elsewhere. In fact, the association seems to be characteristically developed in Atlantic provinces, i.e. igneous regions lying outside the orogenic belts, and its constancy forbids that it could be merely fortuitous. Some fundamental principle must be involved. What this may be, however, is at present unknown, but the mutual occurrence of the two rock types appears to be as constant as the association of basalt with trachyte in oceanic islands.

In conclusion, the writer wishes to acknowledge his indebtedness to Professor E. B. Bailey for his help and criticism both in the field and during the development of the ideas expressed in the present paper.

A Zeolite-filled Cavity in the Igneous Rock of Croft, Leicestershire.

By F. Jones, M.Sc., F.G.S., and S. Langley, B.Sc.

DURING an intensive investigation of the joint phenomena of the South Leicestershire igneous intrusions a widened joint cavity eighteen inches long and five wide apparently filled with "calcite or quartz" was noted. On closer examination the mineral showed perfect trapezohedra of analcime and cube-like rhombohedra of chabazite. The analcime crystals attained a diameter of 0·4 inches: they comprised the bulk of the specimen, the chabazite being very subordinate and only in small sizes. As is usual the analcime had preceded the chabazite in order of crystallization. The cubic mineral was colourless, milky white, and also reddish through impregnation with iron oxide. The chabazite was opaque white but translucent on fracture.

The position of the zeolite-filled cavity was some eighty feet deep in the rock. A reddened stringer led up at a low angle to and beyond the cavity. Further search on the day of discovery failed to reveal any other specimens, but there are strong indications that the rock from the lowest working may be or may have been impregnated with zeolitic material.

The Croft rock (described in detail in the recent Coventry Sheet Memoir) is perhaps the most siliceous member of the "diorite-porphyries" which emerge from the Triassic mantle of South Leicestershire: the occurrence of analcime and chabazite is unexpected and therefore remarkable. As far as the authors can discover zeolites have not been previously found in any of the Leicestershire intrusions.

In view of the fact that analcime is generally associated with alkali (soda-rich) basic rocks and that the field evidence points to impregnation from below, the occurrence seems especially interesting. The authors are pursuing their inquiry both at Croft and in the similar exposures of Stoney Stanton, Narborough, etc.

On the Contemporaneity of Certain Ammonite Beds in England and France.

By Dr. L. F. Spath.

ON the advice of Prof. L. W. Collet, of the University of Geneva, M. E. Bovier has, for several years now, been studying the Liassic deposits in what he terms the "second range" of the Jura Mountains, north of Bellegarde in the Department of the Ain, France. He collected a large number of ammonites in the quarry at Prébasson, near Champfromier, where the Upper Sinemurian is well developed, especially deposits in the *oxynotum* zone. The stratigraphical details and full lists of fossils have now been published by M. Bovier in a paper entitled "Les Ammonites du Sinémurien supérieur de Champfromier (Jura français)".[1] The object of the present note is merely to direct attention to some facts of importance for the correlation of Liassic deposits, facts that confirm the suspected[2] unsoundness of polyhemeral Liassic chronology. The whole problem of correlation over wider areas is being discussed more fully in connection with higher beds in the Jurassic.[3] M. Bovier compared his ammonites with the Liassic material in the Geological Department of the British Museum, collected in the corresponding Upper Sinemurian beds at Charmouth. For it was Dr. Lang's collection, in the first instance, being the only material available that had been

[1] C. R. Soc. Phys. et d'Hist. Nat. Genève, xlvii, 3, 1930, 122–8.

[2] See discussion on paper by Lang, Spath, etc.: "The Belemnite Marls," *Quart. Journ. Geol. Soc.*, lxxxiv, 1928, 255–7.

[3] Revision of the Jurassic Cephalopod Fauna of Kachh (Cutch). *Pal. Indica*, N.S. ix, 2, part 6.

carefully collected, on which the original[1] subzones (within the *obtusum* zone) were based, as well as the later subdivisions of the *oxynotum* and *raricostatum* zones. I ought to make it clear in this connection that the term zone is here used in its original meaning. Thus d'Orbigny[2] in 1850 already spoke of his Kimmeridgian stage as the " zone of *Ammonites lallieri*, of *Ostrea deltoidea* and *O. virgula*," while Oppel,[3] six years later, wrote of " zones " or " horizons " as being distinguished by the constant and exclusive occurrence of certain species. Therefore the zone is defined by the range or vertical distribution of species (or better an assemblage of organic remains), irrespective of stratal or lithological incidentals. Subzones consequently are smaller divisions of geological time, characterized by the local restriction of certain index species. The value of these local subzones for purposes of an ideal time-scale (Oppel's "ideales Profil"), in my opinion, is nil. If the Champfromier sequence had been worked out before that at Charmouth, the order of Upper Sinemurian " hemerae " (rashly adopted in some text-books) would have been very different. It is clear that the restricted occurrence of any particular ammonite at a given locality is something entirely different from the actual date of existence (range or hemera) of this species.

There was, of course, no justification for Oppel's sweeping statement that each horizon, characterized at one locality by a number of constant species, was to be found again with equal certainty even in the most distant areas. Waagen, in applying Oppel's teaching to the Jurassics of Kachh in India, helped to popularize the assumption, often tacitly made, that ammonite zones are of world-wide extent ; but it was just the analysis of the Kachh cephalopod fauna that has now yielded striking evidence against the different species having spread simultaneously to different localities. That is to say, disregarding the warning of Forbes, Huxley, and later defenders of homotaxis, we got into the habit not only of measuring all successions by European standards, but of relying on a scheme of zones based on what the distribution of ammonites might have been, if arranged specially for our convenience. Nevertheless, so far as the present Lias sequence is concerned, the zones of *Oxynoticeras oxynotum* and *Echioceras raricostatum* recognized by Oppel many years ago are still useful divisions of Sinemurian time and, interpreted sufficiently widely, can be traced at least as far as Mexico, whence Burckhardt[4] has recently recorded the occurrence of *Echioceras* and *Eoderoccras* and other genera mentioned

[1] W. D. Lang : " The Geology of the Charmouth Cliffs, etc.," *Proc. Geol. Assoc.*, xxv, 1914.

[2] Paléontologie Française. Terrains Jurassiques (1842–51), p. 610.

[3] See Oppel : " Die Juraformation, etc." *Württ. naturw. Jahresh.*, xii, 1856, 3.

[4] Etude synthétique sur le Mesozoïque mexicain. *Mém. Soc. Pal. Suisse*, xlix–l, 1930, 19.

below in an order which must seem incredible to the adherents of polyhemeral chronology. Little has been gained by Buckman's attempt to provide for these two zones new labels ("Deiran" and "Raasayan"), but their substitution by (misnamed) "Oxynoticeratan" and "Deroceratan" ages, with 31 fictitious "hemerae", is still more out of proportion.

The beds in the *raricostatum* zone at Champfromier are largely obscured by vegetation, but in the poorly preserved uppermost assemblage (16) collected, M. Bovier has already noticed representatives of *Eoderoceras* and *Hemimicroceras*. The next lower limestone band (15) is full of typical *Echioceras* of the *raricostatum-zieteni* group, but the ammonites are too closely packed, vertically as well as horizontally, for the separation of distinct layers by the collector. This, of course, does not disprove the existence of four or even ten separate assemblages in the English *Echioceras* beds[1]; but forms of the *tardecrescens* type which were taken to be characteristic of the higher *Leptechioceras* beds, until Mr. K. G. Blair found one on the Dorset coast, have been discovered at Champfromier below the typical *Echioceras*, instead of above. These *tardecrescens* marls (14) have also yielded *Gleviceras* which the writer[2] has already stated to be found throughout the lower *raricostatum* zone, whereas Buckman took it to characterize a horizon in the *oxynotum* zone below.

A succession of limestone bands and marls (beds 13–2) representing a thickness of about 18 feet, which M. Bovier considers to be within the *oxynotum* zone, has yielded several forms at horizons above those to which they had been thought to be restricted, while others at Champfromier appear in lower beds. Taking five common ammonites used by Buckman to denote "hemerae" in the Oxynoticeratan age, it may be shown in the following table how they occur at Champfromier:—

(*a*) Buckman's 12 "hemerae" (Oxynoticeratan age).	(*b*) Champfromier, beds 13–2 (E. Bovier).
(*l*) . . .	(13) . . .
(*k*) . . .	(12) *simpsoni*
(*j*) . . .	(11) *bifer*
(*i*) . . .	(10) . . .
(*h*) . . .	(9) . . .
(*g*) . . .	(8) . . .
(*f*) *oxynotum*	(7) *lacunata*
(*e*) *bifer*	(6) . . .
(*d*) *simpsoni*	(5) *gagateum*
(*c*) *gagateum*	(4) . . .
(*b*) *lacunata*	(3) *oxynotum*
(*a*) . . .	(2) . . .

[1] Trueman and Williams: "Studies in the Ammonites of the Family Echioceratidae." *Trans. R. Soc. Edinb.*, liii, 1925, 736.

[2] Spath: "Notes on Yorkshire Ammonites," no. iii, *Naturalist*, June, 1925, 168.

With reference to the list (*b*) I ought to add that *O. oxynotum*, for example, is not confined to bed 3, but goes up into 12, so that it is not a case of Buckman having gone wrong merely in listing his hemeral ammonites in the wrong order.[1] Moreover, in bed 10 at Champfromier *Hemimicroceras subplanicosta* (Oppel) appears, and beds 8 and 9 have yielded *Eoderoceras* of the *bispinatum* type, both assumed to mark horizons in a different and later age and placed by Buckman above his *densinodulum* " hemera " at the base of the *raricostatum* zone. This *Crucilobiceras densinodulum*, however, at Champfromier again occurs together with *Oxynoticeras simpsoni* and other species of the same genus. These facts cannot be explained away by assuming " non-sequences " and they show that Buckman's hemeral " chronology " is useless ; in the Upper Jurassic he was even more astray.[2]

In the lowest bed exposed (No. 1), a marly limestone, fairly well-preserved *Asteroceras*, have been found by M. Bovier, including *A. smithi* (J. de C. Sowerby) and *A. marstonense*, Spath. These forms belong to the *stellare* beds or upper *obtusum* zone, but at Champfromier they are associated with other ammonites, e.g. *Schlotheimia rumpens* (Oppel), which still occurs in the *oxynotum* zone (beds 2, 4). Since the lowest bed 1 rests directly on Triassic marls, there is a possibility of explaining this assemblage of ammonites of presumed different horizons by some ingenious process of derivation from pre-existing and denuded beds ; but *Epophioceras landrioti* (d'Orbigny) which according to Dr. Lang's material, occurs in Dorset below *Asteroceras stellare*, is found together with *Schlotheimia lacunata* in bed 6 at Champfromier, i.e. somewhere about the middle of the *oxynotum* zone.

I may add that M. Bovier has a number of forms of Alpine affinities ; for example, in the lowest bed (1) there occurs a Rhacophyllitid quite unknown from the English Sinemurian. The species of *Echioceras*, *Eoderoceras*, etc., also are those described by Hug [3] from the Stockhorn district, and by Geyer,[4] from the Hierlatz near Hallstatt. This may at once suggest to the defenders of Buckman's methods that the identifications are " not accurate enough ". I have repeatedly pointed out that it was chiefly by his insistence on a spurious precision that Buckman made the study of ammonites distasteful to the younger generation ; and now I see that Dr. Seitz [5] even considers our " scientific " ammonite

[1] Buckman always disarmed criticism by pointing out that his " hemerae " *may be* in the wrong order.

[2] See e.g. Spath : " Notes on Yorkshire Ammonites." *The Naturalist*, Nov., 1926, 325.

[3] " Beiträge z. Kenntnis der Lias- und Dogger Ammoniten, etc." *Abhand. Schweiz. Pal. Ges.*, xxvi, 1899.

[4] " Ueber die Liasischen Cephalopoden des Hierlatz." *Abhandl. K. K. Geol. Reichsanst.*, xii, no. 4, 1886.

[5] " Kritische Bemerkungen zur homöomorphen Ammoniten-Terminologie." *Jahrb. Preuss. Geol. L. A.*, l, 1929, 153.

terminology a step backward rather than an advance. It would be easy to take three adult examples of a common species like *Oxynoticeras oxynotum* (Quenstedt) from Cheltenham, Ofterdingen and Champfromier, and by means of the exaggeration of graphs and worthless differences in the ontogenetic development or in the suture-lines (of one side or the other or from selected septal edges) to satisfy some that these three specimens really belong to three different species, if not genera. But it is time the study of Jurassic stratigraphy ceased to be impeded by methods that do not allow of a single observation of the earlier geologists to be accepted or of a single fact to be explained in a simple and straightforward manner; and the writer hopes that M. Bovier's (and Dr. Burckhardt's) work may lead to the publication of detailed Liassic sequences from yet other areas. They will undoubtedly show still more different vertical distribution of the so-called "hemeral" ammonites within the larger zones; but it is only by patient accumulation of facts and not by rash assumptions that real progress will be made and confidence in zonal palaeontology will be restored.

REVIEWS.

GEOLOGIE DER INSEL ISCHIA. By A. RITTMANN. Ergänzungsband vi zur Zeitschrift für Vulkanologie. viii + 265 pp., with 12 plates, 2 maps, and 55 text-figures. 1930.

ALTHOUGH Ischia is one of the most famous of the Italian volcanic districts, we have here for the first time a complete account of its vulcanology, structure, geological history, and petrography. The island is built entirely of tuffs, tuffites, and lava-flows. Activity is confined at the present time to fumaroles and hot springs, and the only dated eruption is that of A.D. 1302, which produced the well-known Arso lava; but the voluminous bibliography (beginning with Pindar) contains allusions to various eruptions between 500 B.C. and A.D. 300. The history goes back much farther, for the fossil-lists, here set out in full, indicate three different stages in the Pliocene and two in the Pleistocene.

From the almost complete absence of older rocks among the ejected blocks, it is inferred that the source of the volcanic material is situated at no great depth, and this is held to be confirmed by the close spacing of the lines of fracture and of the numerous volcanic centres. The author pictures an underlying reservoir of laccolitic habit, at a depth of not more than two kilometres, this being itself an offshoot from the more deep-seated "Campanian batholite", which underlies the neighbouring mainland. Partial consolidation and magmatic differentiation were already in progress before, in Pliocene times, collapse of the roof initiated vulcanicity on the submerged site of Ischia. Here submarine flows, varying from trachy-basalt to trachyte, were poured out at several places. These rocks are found as blocks enclosed in the tuffs erupted during the next episode. These are the Epomeo trachyte-tuffs, which attain a great thickness, and constitute the most important formation of the island. There followed an upheaval which is attributed to an intrusion of abundant fresh magma into the subjacent reservoir. In the subsequent history, extending through Pleistocene and Recent times, Ischia was broken into several districts, in which events developed on somewhat different lines. Monte Epomeo and the surrounding high land behaved as a "horst". An important line of vulcanicity followed the "Tyrrhenian fracture", running in a south-westerly direction from near Ischia town on the east coast. North of this is a sunken tract including Monte Rotaro and other centres. In the south-east is the Monte Campagnano district, in the south-west that of Punta dell' Imperatore, and in the north-west that of Lacco-Ameno with Monte Vico and the lava-plateau of Zara.

The numerous eruptions of lavas and tuffs which are distinguished show a gradual change in their composition. Phonolites are succeeded by phonolitic sodalite-trachytes; then come plagioclase-trachytes and trachytoid sodalite-trachytes, trachy-andesites, and trachy-basalts, and finally the vulsinite (or ciminite) of Arso. The ejected blocks include also various syenites and monzonites, with corresponding hypabyssal types, besides olivine-gabbros and lamprophyres. All these rocks are fully described in the petrographical part of the memoir, which includes twenty-four new chemical analyses. The illustrations comprise a large coloured geological map on the scale 1 : 10,000, and a number of well-chosen photographs, worthy of a work which will be welcomed as a valuable contribution to Italian geology.

A. H.

A Year on the Great Barrier Reef. By C. M. Yonge. London: Putnam. 21*s*.

THE work of Davis, published in 1928, has once again attracted attention to the Coral Reef Problem, while the activities of the Great Barrier Reef Expedition of 1928–9 have focussed that attention upon the Queensland formations. The scientific reports of the expedition are being issued in various publications, but in this volume Dr. Yonge, the leader of the Expedition, has aimed at conveying to the non-scientific reader an idea of the nature of the Barrier and of the problems connected with it. His account has many of the disadvantages inherent in "popular" books upon scientific subjects. Its last few chapters are irrelevant and one fails to obtain a clear picture of the reef as a whole. The main camp of the party was located on "Low Isles" (16° S.) and accordingly the geographical description of the reef suffers from this concentration of interest. But despite these things, the book is a good one. Its collection of photographs, seventy in all, most of which were taken during 1928–9, make it a useful companion. The chapters range from a summary of the various theories which have attempted to explain the origin of coral formations to an account of modern pearling operations on Thursday Island. The outstanding sections are those dealing with the Biology of the Reef and the organic processes of corals. The chapters on reef-destruction and on the experiments upon Corals make good reading. As an informal account of an important expedition, the book is full of interest.

H. C. D.

THE GEOLOGY OF THE COUNTRY BETWEEN GATOOMA AND BATTLEFIELDS. By A. M. MACGREGOR. Southern Rhodesia Geological Survey, Bulletin 17. Salisbury, 1930. 4*s.* 9*d.*

THIS memoir contains the results of the survey of an area of some importance in the Rhodesian goldfield, though not of the first class, since the Cam and Motor mine, the largest producer, and the Globe and Phœnix and Gaika mines are just outside its limits to the north and south respectively. Nevertheless, the numerous small mines have produced some millions worth of gold up to date. The geology is of the usual type: namely a Pre-Cambrian complex of volcanics and sediments with two large granites of different ages, some dolerite dykes, referred to both the Bushveld and the Karroo phases, and alluvium. The gold occurs in numerous small quartz veins with very variable strikes, which are most abundant in granite country, contrary to the general belief.

There is an excellent coloured geological map and the plates are particularly well reproduced.

BEZIEHUNGEN ZWISCHEN KRISTALLISATION UND DIFFERENTIATION IN BASALTISCHEN MAGMEN. By E. LEHMANN. *Min. Pet. Mitt.* xli, Heft 1, pp. 57. Leipzig, 1931.

THE author of this paper has previously published descriptions of the basaltic and related rocks of the Stöffel in the Westerwald and of the north end of Lake Nyasa (Konde-Poroto volcanoes). He now proceeds to discuss from the theoretical point of view whether any of these, and if so which, can be taken to represent possible liquids, with special reference to the results obtained by the Scottish Survey in Mull and the ideas set forth by Dr. Bowen in his book *The Evolution of the Igneous Rocks*. In the instances described by the author a special point arises in the heteromorphism exhibited by the actual rocks; that is to say, that under slightly different physical conditions similar magmas may solidify as different mineralogical assemblages (modes) whereas the norms are the same. This leads an impartial reviewer to the reflection that possibly in recent petrological literature too much attention has been paid to what rocks ought to be rather than what they actually are. It scarcely seems permissible in a realistic science like petrology to ignore the physical environment altogether, which is what the modern method of norm calculation comes to in the last analysis, especially as the standard norm is absolutely arbitrary and represents in the vast majority of cases a mineral assemblage found in no known rock. The author here to a very considerable extent gives the case away when he admits in his summary that the physical conditions determining the course of crystallization of an initial basaltic magma as essexite-basalt, atlantite or hornblende-basalt,

also determine the future course of the magmatic development (differentiation) of the remaining liquid along different paths. In plain words, in most petrological discussions the whole stress is laid on analytical chemistry, while physical chemistry is ignored.

When physical conditions in the cases under discussion have favoured the separation from the initial magma of the essexite-basalt type, further progress leads towards trachydolerites and trachytes. Atlantites on the other hand are followed by a development towards tephrites and phonolites. The sequence following the separation of hornblende-basalts as the first stage has not yet been completely followed out, from want of material, but this is believed to lead to the formation of trachyandesites and kenyites.

From this memoir it does not appear that the author has formed a definite opinion as to what may be the nature of the determinative physical factors concerned in each case, although he does suggest in a tentative manner that they may be referable to the presence or absence of volatile constituents. Such might well determine the crystallization of hornblende and biotite rather than pyroxenes and olivine.

Another important point raised is that in the author's opinion Dr. Bowen has pushed somewhat too far the idea that phenocrysts in basaltic rocks are necessarily of extraneous origin, and not derived from a liquid having the same bulk-composition as the rock of which they now form part. The chief argument employed is that some of the heteromorphs here described are porphyritic and some are not, while each may yield exactly the same analysis: it is therefore concluded that some of the porphyritic forms do correspond to the composition of a liquid, without accumulation of foreign phenocrysts. This seems sound reasoning. Nevertheless it is not disputed that Dr. Bowen's idea applies in many instances.

R. H. R.

At its General Meeting on 13th February, the Geological Society of Vienna conferred its honorary membership on Mrs. Ogilvie-Gordon, in recognition of her distinguished work on fossil corals, and especially in connection with the geological structure of the Dolomites of the Southern Tirol. There are only six other honorary members of this Society.

CORRESPONDENCE.

LARGER FORAMINIFERA FROM THE TERTIARY OF SOMALILAND.

SIR,—Please allow me to protest against some remarks affecting myself, which appeared in a paper under the above heading by Dr. W. L. F. Nuttall and Mr. A. G. Brighton, in your issue for last month (February, 1931). Thus, on p. 56 of the same, these authors challenge my reference of the Kohat Shale to the Laki on the grounds that it contains *Nummulites laevigatus*, *N. perforatus*, *N. atacicus*, *Ass. exponens*, and *A. spira*. The authors say: "In our opinion, this assemblage of *Nummulites* and *Assilina* would be regarded by all authorities as typical of strata of Lutetian age." Of course it would; and since they leave the matter at that, they deliberately imply that I suggested a Lower Eocene age for the Kohat Shale in the face of all the evidence. I wish, therefore, to make it clear that the reason why I referred the Kohat Shale *as a whole* to the Laki was that the more definitely Khirthar (or Middle Eocene) forms, such as *N. laevigatus*, *perforatus*, etc., only come in at the top of nearly a hundred feet of sediments—whereas (to mention only a few facts) the palaeontologists at Calcutta had identified such typical Laki forms as *Alv. oblonga* and *Ass. granulosa* as characterizing the great bulk of the bed, while crowded *A. leymeriei* had also been identified in the lower levels of it.[1] Thus, as I pointed out, the fauna appeared, though mixed, to be of Laki character on the whole, the characteristically Khirthar forms coming in only at the summit of the formation. All this Messrs. Nuttall and Brighton ignore. They quote my Khirthar forms as if they characterized the entire bed, omit all reference to my Laki ones, and then calmly propose that I had "no justification" for holding that *kohaticus* occurs in beds of Laki age—a statement which the bare mention of *oblonga*, *granulosa*, and *leymeriei* would have been sufficient to refute.[2] I think that some indignation is excusable on my part. (There is much more I would like to say, but I will not encroach further upon your space.)

L. M. DAVIES.

LEITH FORT,
EDINBURGH.
7th March, 1931.

[This letter has been shown to Mr. Brighton, who replies as follows.]

[1] See, for instance, pp. 198–207 of *Trans. Min. and Geol. Inst. of India* for February, 1926.

[2] On Nuttall's own showing, these forms have never been found outside of the Laki, or Lower Eocene, in India.